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ABSTRACT

The principal publications the Arkansas Energy Office offers to the public on energy conservation, solar energy, and renewable energy resources are presented in this one volume for convenient reference. These publications are organized under the following headings: (1) retrofits for conservation; (2) solar energy; (3) active solar energy; (4) passive solar energy; (5) wind; and (6) biomass. Annotated bibliographies of energy publications and films available through the Arkansas Energy Office are included in appendices. (JN)

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Insulate & Save Energy; Cut Taxes

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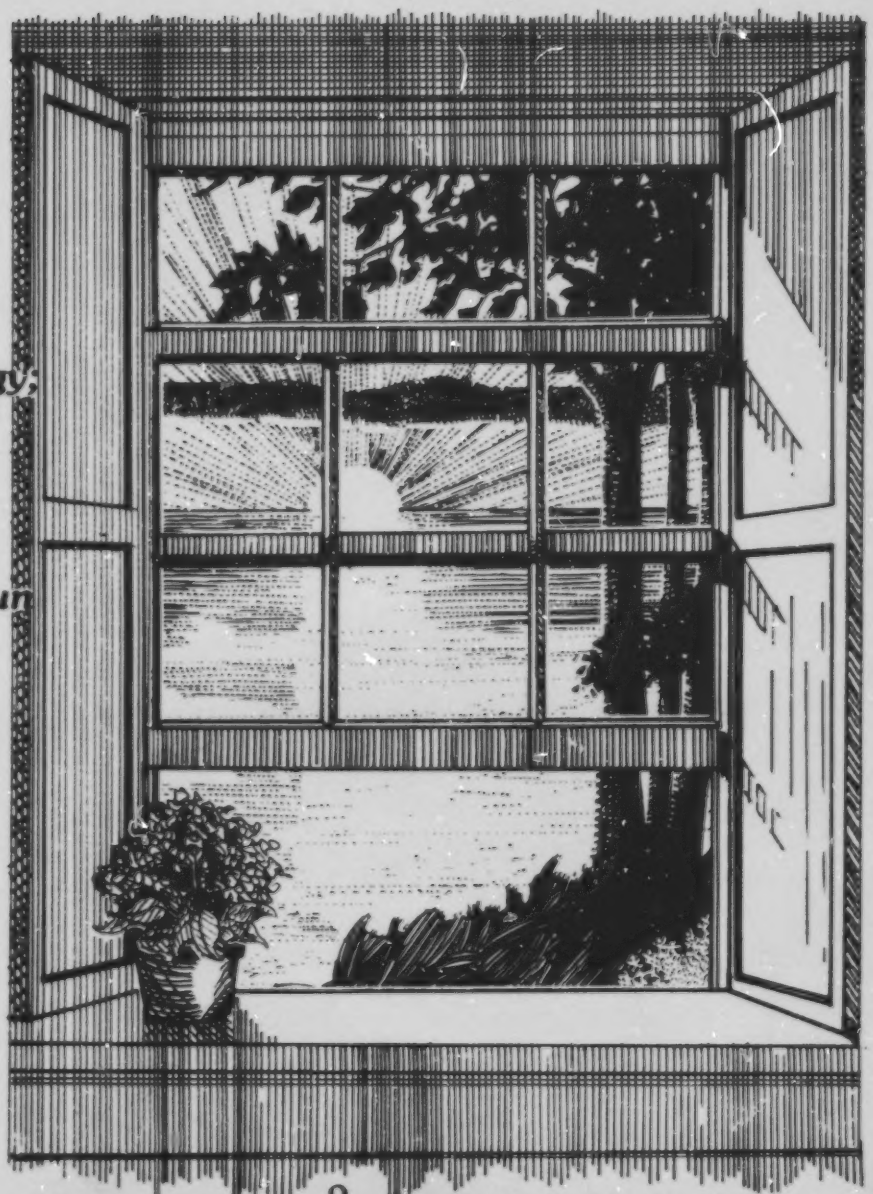
Use Natural Heating and Cooling



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Introduction

The principal publications the Arkansas Energy Office offers to the public on conservation, solar and renewable energy are collected in this one volume for convenient reference.

All the sections of this book are also available separately without charge from the Energy Hotline: 1-800-482-1122. Most sections were prepared by agency employees. Authors of major works are identified in the Table of Contents. The section on Air Heaters was prepared by the Office of Human Concern at Rogers, Arkansas.

Free! New and Improved Energy for Arkansas is intended as a companion volume for *Achieving Self-reliance: Backyard Energy Lessons*, a report on appropriate technology projects established by individuals in Arkansas from 1979 to 1983.

Both volumes may be found in libraries throughout the state, along with the Energy Resource Kits distributed by the Energy Office in 1982. They are also available to the public through the Energy Hotline.

1 Retrofits for Conservation

Tips for Energy Savers

Heating and cooling in a home consume 70 percent of all energy used. The first step in controlling utility bills, therefore, is to control heating and cooling costs.

INSULATION

Adding insulation could cut energy usage in your home by 20 to 30 percent, so check out the insulation already in place and consider adding more. Measure the inches and check the type of insulation in the attic and underneath the floor. Unscrew an electric wall outlet cover on an exterior wall, and use a flashlight to see whether there is insulation in the walls.

The Arkansas standard for home insulation calls for:

R-30 in the ceiling
R-19 in the floor
R-19 in exterior walls
R-4 for unheated slab floors
R-6 for heated slab floors
Six-mil black polyethylene as a ground cover in the crawl space for a vapor barrier
R-7 for air-conditioning ducts

R stands for the insulating material's resistance to the flow of heat through the material. By law, each package of insulation must have its R rating listed. Check the package when you buy insulation and be sure you are getting the proper amount.

If you plan to purchase insulation and have it installed, get at least three bids, and ask for the name of satisfied customers of the companies.

If you plan to buy cellulose, look for the federal government label (HHI-315-D) that shows it has been inspected.

If you plan to install insulation yourself, learn about proper methods first. Consult:

The Women's Energy Tool Kit

"Saving Energy Dollars," published in the October 1981 issue of **Consumer Reports.**

TYPES OF INSULATION

DUCTS

R-7	Glass fiber, foil-backed

CONSTRUCTING CONCRETE FLOORS

R-4	1" Styrofoam
R-6	1½" Styrofoam

BATTS OR BLANKETS

	Glass Fiber	Rock Wool
R-11	3½"-4"	3"
R-19	6"-6½"	5¼"
R-22	6½"	6"
R-30	9½"-10½"*	9"*
R-38	12"-13"*	10½"*

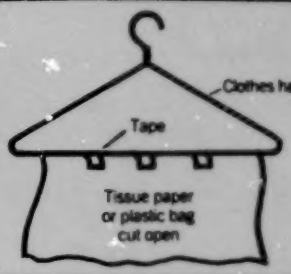
LOOSE FILL (POURED IN)

	Glass Fiber	Rock Wool	Cellulosic Fiber
R-11	5"	4"	3"
R-19	8"-9"	6"-7"	5"
R-22	10"	7"-8"	6"
R-30	13"-14"	10"-11"	8"
R-38	17"-18"	13"-14"	10"-11"

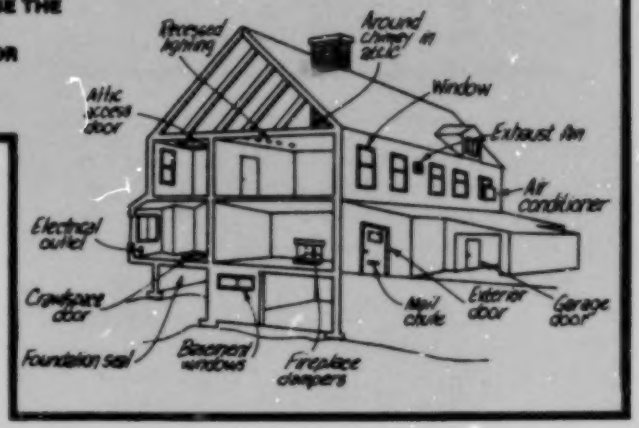
*Two batts or blankets required.

AIR LEAKS, CAULKING AND WEATHERSTRIPPING

Air leaks let in summer heat and winter cold, so search them out and plug them up. This could cut energy usage in your home by 25 percent annually. Make yourself a draft detector to check for leaks. Clip tissue paper or thin plastic over a coat hanger and hold it in front of cracks around doors and windows. Any movement of the paper or plastic indicates an air leak.



WHERE TO USE THE DRAFT DETECTOR



CHECKLIST OF HOUSE LEAKS

- ☐ Basement windows
- ☐ Basement ceiling — holes cut for wires and plumbing
- ☐ Basement door/crawl space
- ☐ Heating ducts in crawl space
- ☐ Exterior lights, electrical outlets, and water pipes
- ☐ Baseboard molding
- ☐ Windows — sashes, frames, and trim
- ☐ Doors — mail slots and glass panels
- ☐ Sliding glass doors
- ☐ Fireplaces, dampers
- ☐ Heating registers
- ☐ Electrical wall outlets
- ☐ Built-in cabinets in kitchen or bathroom
- ☐ Window air-conditioning units
- ☐ Ceiling/wall light fixtures
- ☐ Beam/drop ceilings
- ☐ Attic floors — holes cut for wires and plumbing
- ☐ Attic trap doors
- ☐ Around chimneys

WINDOW COVERINGS

One low-cost method of keeping out the cold in winter and the sun in summer is to install insulating window shades, shutters, or curtains.

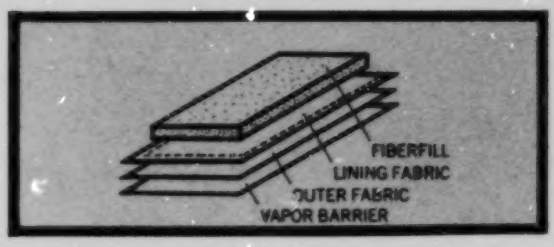
Be sure your insulating window material has these features:

* A firm, tightly-woven fabric such as duck, seersucker or kettlecloth for the outer covering, facing the room, to hold the insulation in place.
* A light-colored lining that is resistant to sunlight and moisture, facing the outside.
* An insulating material such as an air space,

polyester fiberfill in sheets or plastic bubble film between the inner lining and outer covering.

* A vapor barrier to prevent moisture from condensing on windows, such as 4-mil polyethylene plastic or clear vinyl.

* Seals around the edges to prevent air flows, such as self-stick magnetic strips, Velcro® strips, button, or wooden side clamps.



For details on making your own window coverings, contact the Home Extension Agent at the Cooperative Extension Service office in your county, or consult *The Women's Energy Tool Kit.*

STORM WINDOWS

Storm windows may be cost-effective once air leaks have been sealed. Storm windows create a dead-air space by placing a second panel over the existing window within a distance of three-quarters of an inch to 4 inches. This panel could be a sheet of plastic taped to the inside window frame or glass panels in frames attached to the outside.

Before you purchase storm windows, obtain bids from at least three companies. Look for windows approved by the Architectural Aluminum Manufacturers' Association (AAMA). Ask for the names of satisfied customers who installed storm windows 12 months ago, and ask them if they are satisfied with the job done for them.

Before you install your own storm windows, consult:

Women's Energy Tool Kit

CAULKING AND WEATHERSTRIPPING

Seal air leaks with caulking or weatherstripping. Caulk points that have no moving parts, such as a foundation crack at the joint with the upper part of the house.

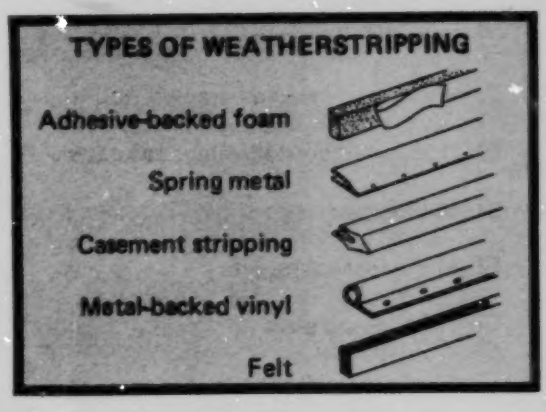
Caulks last 3 to 20 years. A middle-grade caulk is generally a good buy. Consider these features in purchasing caulk:

Silicone or acrylic latex caulk lasts 10 to 20 years.
Butyl rubber caulk lasts 4 to 10 years.
Latex caulk lasts 3 to 10 years.
Oil-based caulk lasts 2 to 3 years.

Install weatherstripping to close air leaks betwen moving and non-moving parts. Weatherstrip placed on the non-moving part is flexible and seals doors, windows, mail chutes and similar places around the house.

Plan to buy a medium-quality weatherstrip, which should last 3 to 5 years. Consider these features before you buy:

Self-adhesive foam lasts 1 to 2 years.
Foam with wood back and nails lasts 4 to 5 years.
Wool felt lasts 2 years.
Felt with metal backing and screws lasts 3 to 5 years.
Vinyl with wood backing and nails last 5 years.
Vinyl or rubber bulb with aluminum and nails lasts 5 years.
Flat metal lasts 5 to 8 years.
Plastic with adhesive strip lasts 5 years.



To learn how to install caulking and weatherstripping, consult:

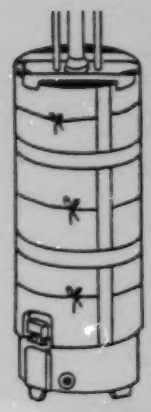
Weatherstripping vs. Caulking
Find and Fix Air Leaks
Women's Energy Tool Kit

WATER HEATERS

Heating water accounts for about 20 percent of all energy used in the home. Cut out waste and cut your energy consumption.

* Reduce your water-heater thermostat to 120 degrees, unless you have a dishwasher, and then follow the manufacturer's instructions.
* Repair leaks promptly.
* Use cold water for all rinses when doing household chores.

Insulate the water heater and pipes within three feet of the water heater. Commercial insulation kits are available at discount and hardware stores for both gas and electric water heaters.



PROPER INSULATION ON A GAS WATER HEATER

Be sure to cut out a patch over the controls, to prevent a fire hazard. Do this for both gas and electric water heaters.

Buy insulation to cover the first three feet of pipe coming out of the water heater. One variety snaps in place over the pipe for easy installation; another kind includes an electric wire to heat the pipe. This pipe insulation will cut down on heat losses into the air.

NO-COST ENERGY TIPS

* Keep the thermostat at 78 degrees in summer. Turn off the air-conditioning when leaving the house vacant during a work day.
* In winter, keep the thermostat at 65 degrees in daytime and 55 degrees when you go to bed for the night or leave the house for the work day.
* Close off unused rooms or shut off vents sending hot or cold air to these rooms.
* Control use of ventilating fans so all the air in the house is not blown outside.
* Keep the damper closed when the fireplace is not in use. Add an airtight screen over the fireplace so air is not leaked up the chimney.
* Open drapes and shades to admit winter sun. Close them to keep out summer sun, or winter cold at night.
* Clean the track on sliding glass doors; dirt here can throw the doors out of alignment and cause an air leak.
* Keep doors closed to the attic or basement.
* Change filters monthly on the central heating/cooling unit.
* In summer, use fans for cooling instead of air-conditioning or to supplement air-conditioning.
* Turn off the lights when you leave the room.
* Shade the outdoor condenser of the air-conditioner with a tree or shrub without blocking the flow of air. This makes the unit operate more efficiently. Be sure to keep trash and leaves cleaned out of the condenser.
* Turn off the furnace gas pilot light for the summer. Do not forget to light the pilot again for winter use.
* Dress to suit the temperature. Try skirts instead of slacks for summer. A short-sleeved shirt is cooler than long sleeves. In winter, add a sweater to keep warm, and dress in layers.
* Use fluorescent bulbs if possible.

* Use a lower wattage for incandescent bulbs; they give off heat as well as light.
* Run the dishwasher only when full; dry dishes in air, not mechanically.
* Use hot water only for washing diapers, cotton, or badly-soiled clothes; for the rest, use warm water. Always rinse clothes in cold water.

FOR MORE INFORMATION

For more information on insulation, caulking, storm windows, and window coverings, see:

The Women's Energy Tool Kit, published by Consumer Action Now, 110 West 34th Street, New York, New York, 10001. $7.45. 76 pages.

"Storm Windows", published in the September 1980 issue of **Consumer Reports,** Back Issue Department, Box 1949, Marion, Ohio, 43305. $1.50. 4 pages.

For more information on window insulators, caulking, weatherstripping, water heaters, wood stoves, thermostats and other energy-saving devices, see:

"Saving Energy Dollars", published in the October 1981 issue of **Consumer Reports,** Back Issue Department, Box 1949, Marion, Ohio, 43305. $1.50. 32 pages.

For more information on caulking and weatherstripping, see:

Weatherstripping vs. Caulking, published by NCAT, Box 3838, Butte, Montana, 59701. 40 cents. 12 pages.

Find and Fix Air Leaks, published by the U.S. GPO, Code 1981-341-065/161, Washington, D.C., 20402. $2.25. 28 pages.

Check your local Extension Service office for more on insulating windows.

Ask for these books and magazines in your public library; they may order them if you request it.

Check Your Home Energy Consumption

A simple calculation using the energy consumption recorded on your utility bills will show whether your home is energy efficient, or wasting money.

Take a minute to get out all your electric bills and gas bills for the past 12 months, and list them in a column — add up the year's cost, and the year's consumption of kilowatts, or quantity of gas your family used.

To obtain a single figure showing total energy consumption, perform these calculations (see also worksheet on next page):

1. Multiply the year's kilowatts times 3,412 to obtain the British thermal units, or Btu's consumed.
2. Take the year's total consumption of natural gas, and multiply the thousands of cubic feet times 1,030,000, to get the gas Btu's consumed.
3. If your home uses propane, multiply the gallons of propane consumed times 96,600 to get the propane Btu's consumed.
4. Add together all the Btu consumption figures.
5. Divide the sum by the number of square feet of housing that is heated and cooled. That results in the number of Btu's per square foot consumed in a year's time.

Compare your energy consumption to the chart:

Under 50,000 Btu's wins you an A.....	**YOU HAVE AN ENERGY EFFICIENT HOME.**
From 50,000 to 80,000 Btu's gives you a B.....	**YOU ARE TRYING.**
From 80,000 to 120,000 Btu's gives you a C.....	**THIS IS THE AVERAGE CONSUMPTION AMONG TODAY'S HOMES.**
From 120,000 to 175,000 Btu's give you a D.....	**YOU CAN DO BETTER AND SHOULD GIVE YOUR HOME AN ENERGY CHECK.**
From 175,000 Btu's on up wins you an F.....	**YOU ARE THROWING AWAY MONEY.**

For information on how to detect energy waste in the home, and the cost-efficient methods of controlling high utility bills, write the Arkansas Energy Office.

ENERGY CONSUMPTION RECORD

	ELECTRICITY	NATURAL GAS	PROPANE
JANUARY	$ _____ _____ KWH	$ _____ _____ MCF	$ _____ _____ GAL
FEBRUARY	$ _____ _____ KWH	$ _____ _____ MCF	$ _____ _____ GAL
MARCH	$ _____ _____ KWH	$ _____ _____ MCF	$ _____ _____ GAL
APRIL	$ _____ _____ KWH	$ _____ _____ MCF	$ _____ _____ GAL
MAY	$ _____ _____ KWH	$ _____ _____ MCF	$ _____ _____ GAL
JUNE	$ _____ _____ KWH	$ _____ _____ MCF	$ _____ _____ GAL
JULY	$ _____ _____ KWH	$ _____ _____ MCF	$ _____ _____ GAL
AUGUST	$ _____ _____ KWH	$ _____ _____ MCF	$ _____ _____ GAL
SEPTEMBER	$ _____ _____ KWH	$ _____ _____ MCF	$ _____ _____ GAL
OCTOBER	$ _____ _____ KWH	$ _____ _____ MCF	$ _____ _____ GAL
NOVEMBER	$ _____ _____ KWH	$ _____ _____ MCF	$ _____ _____ GAL
DECEMBER	$ _____ _____ KWH	$ _____ _____ MCF	$ _____ _____ GAL
TOTAL	$ _____ _____ KWH	$ _____ _____ MCF	$ _____ _____ GAL

_____ KWH X 3,412 = _____ BTU

_____ MCF X 1,030,000 = _____ BTU

_____ GAL X 96,600 = _____ BTU

TOTAL _____ BTU

Toll Free Energy Hotline
1-800-482-1122

TOTAL BTU ÷ TOTAL SqFt = BTU/SqFt/Yr

Save Energy; Cut Taxes

ENERGY INVESTMENTS BRING TAX DEDUCTIONS

The total cost of purchasing and installing energy-conservation or alternate-energy devices may be deducted on your individual state income-tax form. This applies to payments made between January 1, 1979 and December 31, 1984, when this law expires.

Deductible are the cost of insulation, solar water-heating systems and the other items listed in the law, as well as the labor cost for installation.

To take advantage of the Energy Saving Deduction, an individual taxpayer must use the **Itemized** Deduction Schedule. The deduction should be listed on the appropriate Energy Saving Equipment Deduction Line and receipts attached, detailing the items purchased and installed.

The deduction may be claimed for equipment added to a building either owned or rented by the taxpayer.

Both owners and renters of buildings located in Arkansas are eligible for this deduction — the one paying for the items is the one who may claim the deduction.

Stockholders of cooperative housing corporations and owners of condominium units may claim a deduction based on their allocable share of qualifying expenditures made by the cooperative housing corporation or condominium management association for the benefit of the common owners. For a stockholder of a cooperative housing corporation, the allocable share of the cooperative's expenditure is proportionate to the stockholder's share of the cooperative's total outstanding stock.

To qualify for this deduction, equipment must be new and must meet performance and quality standards, if any, that are specified by state or federal law or regulation.

Energy conservation items must be expected to last three years.

Renewable energy equipment must be expected to last at least five years.

TAX DEDUCTION EXAMPLES

★ Insulation and storm doors and windows are installed on a home in a $3,000 project, which is financed at a bank. The homeowner pays for the work upon completion, and is entitled to deduct the entire $3,000 from the gross income amount listed in the state income-tax return for that year. The fact that the taxpayer continues to repay the loan to the bank over a period of three years does not affect the right to claim a tax deduction for the expense at the time the homeowner paid for the work.

★ A $3,000 project to add insulation and storm doors and windows to a home is financed through the contractor for the work, over a period of three years. The taxpayer may deduct the amount paid in one year's time from the gross income on the state income-tax form for that year. Interest and finance charges are not deductible as interest expense on the Itemized Deduction Schedule.

★ A solar heating and cooling system and a water-heating system are part of a home that is constructed by a taxpayer, who financed the new home through a 30-year mortgage. The solar system costs $6,000. The taxpayer can deduct this $6,000 from his gross income in the year that he becomes obligated to pay the mortgage debt on the home. At the time of the

sale of the home, the cost of the home must be reduced by this amount.

If you earned $7,000 in the past year and added insulation and storm doors to your home costing $500, then your taxable income would be $6,500 — the gross income amount minus the energy investment deduction. This would lower the tax owed from $142 to $124 and the taxpayer would save $18.

If you earned $25,000 and invested in $1,000 worth of wood stoves, electronic switches on heating systems, or a solar heating system, then taxable income would be reduced to $24,000. The taxes due would drop from $1,080 to $1,023 — a savings of $57.

DEDUCTIBLE PURCHASES

★ ★ ★ Energy Conservation ★ ★ ★

1. Insulation designed to reduce heat loss or heat gain of a building.

Insulation materials include fiberglass, rockwool, cellulose, Styrofoam, urea-based foam, urethane, vermiculite, perlite, polystyrene, reflective insulation and extruded polystyrene foam. These may be installed above ceilings, in walls, under floors, on pipes, underneath roofs, around water heaters, and around forced-air ducts.

2. Insulation for a hot-water heater.

3. Caulking or weatherstripping of an exterior door or window.

Caulking is a flexible material placed in the joints of a building to reduce the passage of air and moisture.

Weatherstripping is a flexible material made in narrow strips that is placed over or in movable joints of windows or doors to reduce the passage of air and moisture.

4. An energy-saving automatic set-back thermostat designed to reduce energy consumption by regulating the demand on a heating-cooling system or water heater.

These devices use a temperature control that incorporates more than one temperature control point and a clock or other mechanism for switching from one control point to another.

5. A furnace burner installed to replace a less energy-efficient burner and designed to achieve a reduction in the amount of fuel consumed as a result of increased fuel efficiency.

These burners may be placed on gas or oil equipment. They mix the fuel with air and ignite the fuel-air mixture. They are part of the furnace, including the combustion chamber. They replace an existing burner. They are designed to reduce the fuel consumed, through more efficient combustion.

6. A device for modifying flue openings that is designed to increase the efficiency of operation of a heating system.

These dampers conserve energy by cutting the flow of air to the chimney when the furnace is not operating.

7. An electrical or mechanical furnace ignition system that replaces a gas pilot light.

When installed in a gas heating system, these devices replace the pilot light.

8. A fireplace door covering.

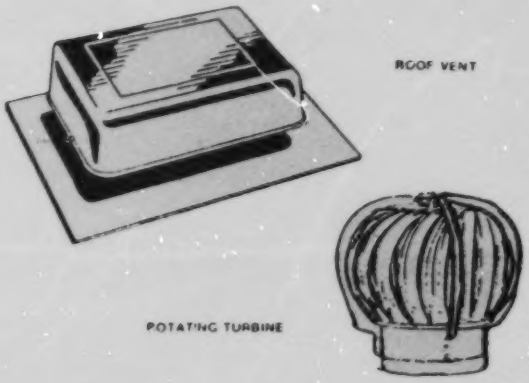
This door, which may be made of glass or other materials, permanently installed over the opening of a fireplace, will prevent the loss up the chimney of warm air from other heating systems, when the fire in the fireplace has gone out.

9. An attic fan.

This is a powered fan permanently installed in a ceiling or fixed to a gable or attic window, that will cool a building in place of other devices.

10. A motor-driven or wind-driven vent.

This vent is a permanently-installed vent, which is specifically designed to increase air ventilation and circulation in normally-unoccupied building spaces. It may be powered by a motor or wind-driven turbine.



11. Equipment and/or measures that enable the taxpayer to reduce or manage electric demand loads in a building.

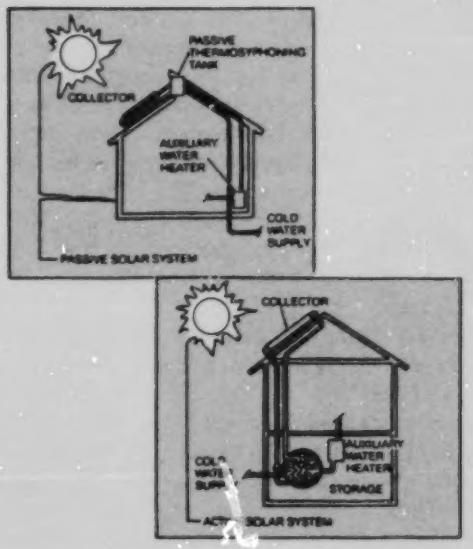
12. Waste-heat-recovery systems that take waste heat from heat-producing equipment or appliances, such as air-conditioning units, and use it to heat water or air.

13. Replacement of lighting fixtures with fixtures that provide the same light but require less electricity.

★ ★ ★ Renewable Energy ★ ★ ★

1. Solar energy equipment that uses the sun to heat or cool a building or provide hot water. Active solar energy equipment consists generally of collectors, absorbers, air or working fluids, heat transfer mechanisms such as ducts or pipes, controls such as thermostatically-operated blowers and dampers, or pumps and valves, storage enclosures and storage tanks, heat exchangers, specialized mounting equipment, and insulation for specific components of the system.

High-efficiency absorption chillers specifically designed to operate in a relatively-low temperature provided by solar collectors and used with collectors also are included.



2. Passive solar material that collects the sun's heat and radiates it back at night.

Window glazing specifically designed to collect the sun's rays, in partnership with movable insulation to cut loss of heat at night, is an example of this material. Storage masses that absorb the heat provided by this glazing and radiate it at night are also included.

Insulation and insulated curtains dropped between a Trombe wall and its associated glazing are other deductible items.

Earth pipes, solar chimneys or ventilation using differential temperatures, and shading devices used specifically to prevent too much heat from being taken into a building through windows are also deductible.

3. Photoelectric or photovoltaic systems in which cells convert sunlight to electrical energy that is used to heat or cool a building or heat water also may be deducted.

4. Equipment that produces methane, methyl alcohol, ethyl alcohol, or other products that may be used to heat or cool a building or provide hot water, which are known as bioconversion property.

This includes equipment for the collection and fermentation of organic materials, as well as their processing and distillation.

Included are anaerobic fermentation chambers and sludge transport mechanisms, gas collection valves, piping, and temperature and pressure-control mechanisms for the production of various alcohols.

5. Hot springs or underground pools, rocks or vapor, known as geothermal energy property.

Equipment may tap this natural feature to heat or cool a building or provide hot water.

6. Hydroelectric power systems.

This includes necessary changes in dams to enable them to generate electricity, such as the construction of sluiceways.

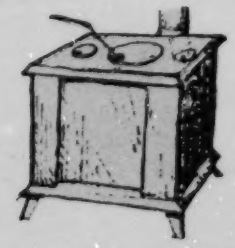
Power recovery equipment such as generators, turbines, water wheels and the like are deductible, as are facilities to store extra power, such as storage batteries.

7. Windmills and other wind energy equipment.

This includes the parts of the windmill, such as propellers, shafts, blades, brakes, and controls. The equipment would be used to convert wind energy into some other form used to heat or cool buildings or provide hot water.

Also included are generators, towers or supports for the wind equipment, wiring, invertors to convert direct current (DC) to alternate current (AC) electrical energy, and storage batteries to store extra power.

8. Wood stoves and furnaces and their parts.



Included are flue pipes, dampers and chimneys necessary for the wood-burning equipment.

Conversion of a traditional fireplace to an enclosed firebox that uses heat exchangers, thermostatically-controlled dampers, blowers and outside air combustion is also deductible.

Heat-recovery units such as flue-heat extractors that recover flue-gas heat that is then used for space heating or water heating also may be deducted.

All installations of wood-burning equipment must meet the specifications of the Arkansas State Fire Code.

ITEMS THAT ARE NOT DEDUCTIBLE

Traditional fireplaces

Heat pumps

Fluorescent light tubes

Coal or peat-burning stoves

Replacement boilers in furnaces

Hydrogen-fuels equipment

Fiberglass roof shingles

Carpets

Drapes

Wood paneling

Exterior siding

Ceiling or window fans

A swimming pool

Any energy storage medium that has a primary function other than the energy storage.

Heating and cooling systems that supplement renewable energy equipment and consume nonrenewable fuels.

FEDERAL SOLAR TAX CREDITS

Residential: As of January 1, 1980, the federal government is offering a **40 percent** nonrefundable tax credit for investments designed to use renewable energy sources in both new and existing residences. This includes technologies for heating or cooling homes, supplying hot water, producing electricity, or harnessing wind or geothermal energy.

The credit applies to investments up to $10,000 a year, yielding a maximum tax credit of $4,000.

The federal credit for energy conservation investments at your home is **15 percent** of the first $2,000 spent, up to a maximum of $300. Eligible items include insulation, storm doors

or windows, caulking or weatherstripping, clock thermostats and furnace replacement burners.

To qualify, the investment must be made by December 31, 1985, but the tax credit may be carried over until 1987. This increases the earlier effective 22 percent nonrefundable tax credit, which began on April 20, 1977.

Business Energy Investment Credits: Businesses can receive a 10 percent refundable tax credit for investments in renewable-resource property installed between October 1, 1978, and December 31, 1979.

On investments made between January 1, 1980, and December 31, 1985, the federal government offers a 15 percent nonrefundable tax credit.

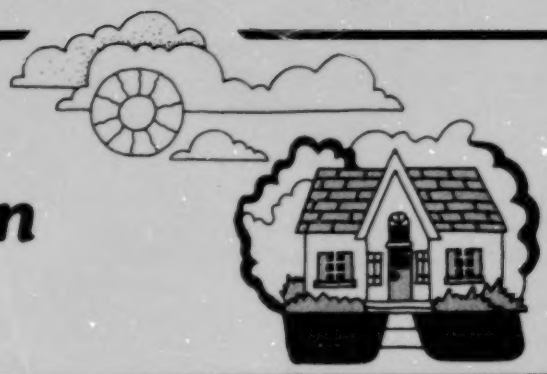
Examples of eligible investments would be solar equipment to heat or cool buildings or to supply hot water, or technology using wind energy.

In addition, the government offers a 10 percent investment credit for biomass property acquired between October 1, 1978, and December 31, 1985. For certain alcohol fuels, a 4-cents-per-gallon excise tax exemption is available to some producers.

Tax laws are complicated; ask the Internal Revenue Service for Publication 903 to learn details of taking credits for home energy investments, or write or call:

Conservation and Renewable Energy
Inquiry and Referral Service
P.O. Box 8900
Silver Spring, Maryland 20907
(800) 523-2929

Residential Conservation Standards



★ **Insulation** ★

Ceiling -- Value of R-30
Exterior Walls -- Value of R-19
Under Floors -- Value of R-19
Unheated Slab Floors -- Value of R-4
Heated Slab Floors -- Value of R-6

A modified roof construction allowing the insulation to extend full thickness to the outer wall sheathing and providing adequate clearance for eave ventilation is recommended. A catwalk above attic insulation is recommended for easy access to the attic space.

Exterior walls must be caulked beneath the sole plate to prevent air leaks. Unfaced insulation batts are recommended for this in conjunction with 2 x 6 wall framing on 24-inch centers. Maximum insulation and minimum wood area in the exterior walls can be accomplished through use of plywood headers for windows and doors.

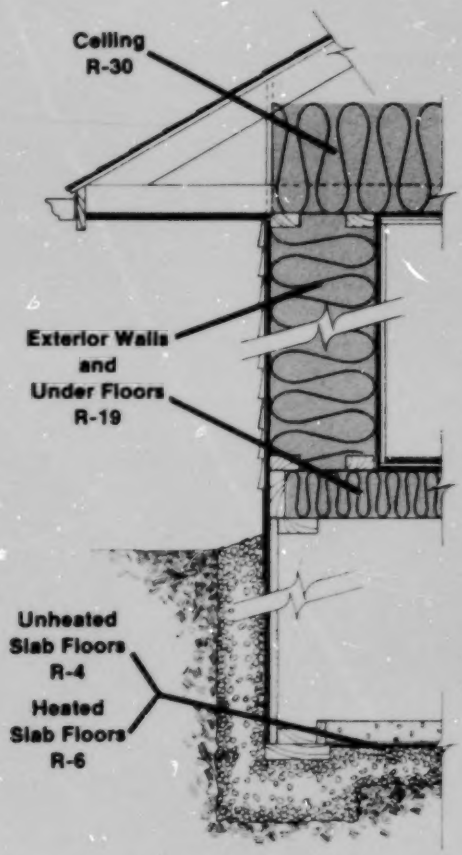
Beneath crawl space floors, use foil-faced polystyrene beadboard installed with foil uppermost, nailed to the bottom of floor joists, or unfaced batts supported by wire clips.

For floating slabs, rigid insulation in an "L" configuration must cover the perimeter face and extend 24 inches beneath the slab around the entire perimeter.

For monolithic slabs, the insulation must extend from finish floor to frost line around the entire conditioned space.

For either type of slab, insulation must separate porches, patios and garages from the floor slabs of conditioned spaces.

Closed-cell rigid insulation is recommended for slab insulation to minimize moisture absorption, and either closed-cell board stock or foamed-in-place varieties may be used.



★ **Vapor Barrier** ★

Six-mil polyethylene, black

Black six-mil polyethylene is recommended as a preferred material for vapor barriers and as a ground cover beneath crawl space floors to prevent earth moisture from entering the structure.

★ Windows and Exterior Doors ★

Not to exceed 15 percent of wall areas for a room
Not to exceed 10 percent of the entire wall area

Windows and doors must not be larger than either 15 percent of the conditioned wall area for any individual room or 10 percent of the entire conditioned wall area.

Prime windows must be fully caulked between window frame and wall sheathing. Windows must be of insulating glass or have a storm window. To minimize air leaks and moisture drops, storm windows are recommended in preference to, or in addition to, the minimum requirement of insulating glass.

The limit on window and door area may be exceeded if the heat loss through transmission and air leaks is not increased beyond 0.18 British thermal units an hour (BTUH)/square foot/° Fahrenheit of design temperature difference for individual rooms and 0.12 BTUH/square foot/° Fahrenheit for the entire conditioned floor area. This might be accomplished by using storm windows over insulating glass or by using insulated doors instead of storm doors.

A storm door is recommended for any exterior door rated less than R-7. A urethane-core door (R-13) with magnetic weatherstrip is recommended in preference to a standard door with storm doors.

Additional window shading, either through extended roof overhang or sun screens, is recommended to reduce equipment size and operating cost and to permit more even temperature balance in rooms having solar gain. A three-foot overhang will usually eliminate 70 percent of the sun's radiation on summer days.

★ Attic Ventilation ★

One square foot for each 300 square feet of attic, with vapor barrier
One square foot for each 150 square feet of attic, without vapor barrier

Attic ventilation should be provided by at least one square foot of net free area (open air space) for each 300 square feet of attic area if an attic vapor barrier is present; or one square foot of net free area for each 150 square feet of attic area with no vapor barrier. The vent area should be equally divided between soffet vents and gable, turbine, and ridge power vents.

For power vents, an adjustable thermostat is recommended, set to come on when the attic temperature reaches 100° F. and to turn off at 85° F. for summer operation. A setting of 10 degrees lower is desirable for moisture control during winter.

★ Air-Conditioning Ducts ★

Insulated to a value of R-7
Vapor barrier overlapped two inches at joints

Heat loss or gain from air-conditioning ducts must be limited to eight percent of the design requirement. Ducts must be constructed of duct board, prefabricated glass fiber duct or sheet metal. All duct joints, including longitudinal seams of metal ducts, must be mechanically secured and sealed.

Ducts outside the conditioned space must have insulation rated at least R-7 with a continuous vapor barrier outside the insulation.

The vapor barrier over wrapped insulation must be overlapped two inches at all joints and seams and taped or cemented in a permanent manner.

The half-inch liner is recommended for ducts within the conditioned space to reduce air noise and prevent condensation.

★ Fireplaces ★

Tight-fitting flue damper
Fresh-air ducts for hearth
Glass firescreen

A tight-fitting flue damper is recommended to minimize loss of conditioned air when the fireplace is not in use.

Wall insulation must be extended to ceiling height either around the fireplace or within a cavity in the fireplace structure. All joints must be thoroughly caulked at intersections of walls with fireplace masonry.

One six-inch or two four-inch fresh-air ducts are recommended with a dampered outlet in the hearth. This allows the chimney to draw without exhausting conditioned air.

A glass firescreen with an adjustable damper

is also recommended to minimize the air flow when the fire is out and the flue damper remains open.

★ Equipment ★

Cooling unit not to be rated more than 10 percent above the calculated requirement

Filter readily accessible

Cooling equipment must not be rated more than 10 percent above the calculated requirement (at 25° design temperature difference) within the manufacturer's standard ratings. This is to improve operating efficiency and humidity control.

Cooling equipment must not be located in the attic space and, for best operation, the air-handling unit should be located within the conditioned space with a readily-accessible filter.

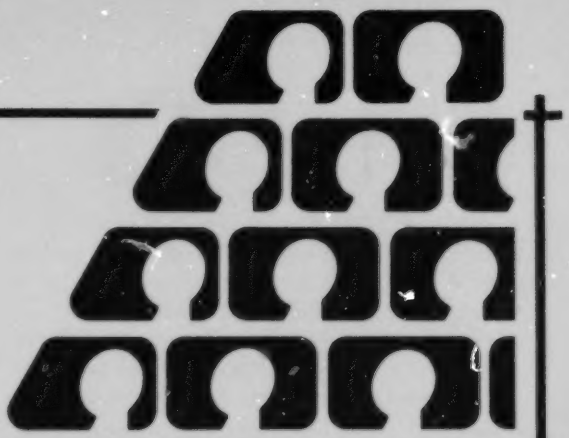
For improved energy efficiency, a heat pump is recommended in preference to an electric furnace.

Where combustion heating systems are used, and located within the conditioned space, outside combustion air should be provided to the system. Ducts or openings for outside air should provide one square inch of opening for each 1,000 BTUH capacity of the heating system.

The efficiency rating (EER) during the cooling cycle is also important, since as much or more energy is required for cooling than for heating.

An electronic filter is recommended to control air quality and to reduce the need for fresh air. A humidifier and dehumidifer are recommended for additional comfort and for more precise control of humidity.

Shareavan



INTRODUCTION

In order to survive and compete with other economies, America must start conserving energy, reducing our need for imported oil. You, however, are already aware of that fact. This summary doesn't reiterate the obvious.

This publication tells you, an employer, in specific terms, how your company can profit from a vanpooling program.

A number of corporations have already implemented successful vanpool programs. That number is growing daily as competitive, efficiency-oriented companies are discovering vanpooling as a solution to many of their problems.

WHAT IS VANPOOLING?

A relatively new concept in ridesharing, vanpooling is sort of a personalized mass transit system, combining the door-to-door convenience of carpooling with the economic advantages of riding the bus.

Here's how vanpooling works:

Generally an employer buys or leases a van that can seat eight to twelve riders. A volunteer driver, one of the employees, is responsible for vehicle upkeep and record keeping. The driver rides free and has personal use of the van for a modest fee. The other riders are picked up at points along the driver's way to work and they pay a monthly fee, which covers the operation of the van, including gasoline, maintenance, insurance, and a payback of the van's initial purchase cost. Eventually, the van is paid for by these monthly fees, at no cost to the company.

WHAT CAN THE COMPANY GAIN FROM A VANPOOLING PROGRAM?

Employee Efficiency

Because vanpooling lets everyone but the driver turn away from the pressure of rush-hour traffic, eight to eleven people arrive at work more prepared to get down to business. They may have already read the morning paper, had their coffee, and mentally thought out the day's work.

Parking Expense

Every successful vanpool eliminates the need for six to ten parking spaces. The average surface parking space can easily cost $2,000 or more to construct, and $200 or more a year for maintenance and taxes thereafter.

Congestion at the Plant Site

Naturally, when traffic into the plant is reduced, congestion around the plant site will be eased.

Reduced Tardiness and Absenteeism

One of the criteria for selecting a van driver is punctuality. If a passenger knows that people will be waiting for him when his commuter van rolls into his driveway, the chances of his being ready on time are increased significantly. That means he'll be on the job when he's expected. The same combination of peer pressure, reliable transportation and improved morale creates a marked reduction in employee absenteeism.

Expanded Labor Force

Workers for whom single-car commuting would be impractical or impossible can reach the plant site easily and economically with vanpooling. It makes available members of one-car families, workers who live in areas not served by mass transit, and those who would otherwise be unwilling to travel to remote company locations. Vanpooling reduces the risk of losing skilled employees should you relocate your plant site. If and when you decide to expand your operations, vanpooling provides you with a larger labor force from which to draw.

Employee Benefits

Vanpooling offers employees a more comfortable, convenient ride to work at a reduced cost. An estimated vanpooling program is an attractive addition to a company's list of benefits, economically comparable to insurance and bonuses.

Public Relations

As energy dilemmas arise, one advantage offered by vanpooling is the part it plays in producing public goodwill and an energy-conscious corporate image. The company is perceived as a leader; aware of society's energy, pollution, and traffic-congestion problems, as well as its own employees' needs. Vanpooling provides the kind of advertising money can't buy.

Having your company name on the side of a van isn't mandatory of course, but it can help you get more mileage from your vanpooling program. In effect, every van with your name on it becomes a moving billboard, seen by thousands of people every day at no cost to you.

HOW DO WE GET STARTED?

Assign someone in your organization to be the coordinator and company representative. The Arkansas Energy Office will help you tailor a program to fit your needs. Consult these organizations for additional information:

National Ridesharing Information Center
Federal Highway Administration
Room 3301-HHP-25
Washington, D.C. 20590
Phone: 202-426-0210

Ed Marks, Executive Director
National Association of Vanpool Operators
12208 West Kingsgate Drive
Knoxville, TN 37922
Phone: 615-966-4507

Arkansas State Employees Vanpool Association
L.D. Owen, Executive Director
1311 West Seventh Street
Little Rock, AR 72201
Phone: 501-378-0187

Rideshare — Central Arkansas Carpooling
Metroplan
800 Wallace Building
105 Main Street
Little Rock, AR 72201
Phone: 501-372-3300

Recycler's Guide

ALUMINIUM RECYCLING CENTERS

Most of the scrap metal companies listed here handle other metals as well as aluminium for recycling. Contact the firms in your area for additional details and prices.

All Safeway stores in Arkansas buy aluminum beverage cans.

BENTON

Saline County Council on Aging
Recycling Center
210 Jefferson
Benton, AR 72015
776-0255

BLYTHEVILLE

Blytheville Iron & Metal Company
1200 South Elm
Blytheville, AR 72315
763-6886

Ed Roleson, Jr., Inc.
Industrial Drive
Blytheville, AR 72315
763-7391

Goolsby Iron & Metal
West Highway 18
Blytheville, AR 72315
763-9086

Robertson Distributing Inc.
615 North Second Street
Blytheville, AR 72315
763-3125

CAMDEN

Harvey's Grocery
Chidester Road - Highway 24
Camden, AR 71701
836-9882

Hunter Iron & Supply Company
150 Center Street, Southeast
Camden, AR 71701
836-2540

CLARKSVILLE

Woodard's Recycling Center
Taylor & Railroad
Clarksville, AR 72830
754-7373

CONWAY

Conway Scrap Metals Company
1110 Spencer
Conway, AR 72032
329-3657

COTTER

Sneed Iron & Metal Company
East Cotter Road
Cotter, AR 72626
436-6300

DERMOTT

Dermott Distributing Co.
300 Iowa
P.O. Drawer A
Dermott, AR 71638
538-5483

EL DORADO

Pesses Iron & Metal Works
423 E & B Streets
El Dorado, AR 71730
862-4928

R.C. Edwards Distributing
621 South Washington
El Dorado, AR 71730
863-8621

FAYETTEVILLE

Abilities Unlimited of NW Ark.
1102 Happy Hollow Road
Fayetteville, AR 72701
521-3500

Hog Country Distributors
1030 South Razorback Road
Fayetteville, AR 72701
442-7410

Coors of Western Arkansas Inc.
750 South Hill Street
Fayetteville, AR 72701
442-6677

FT. SMITH

Miller Reclamation Center
1201 Towson
Fort Smith, AR 72901
783-9247

Davis Iron & Metal Inc.
2610 Wheeler
Fort Smith, AR 72901
783-8831

Yaffe Iron & Metal Corporation
719 Wheeler
Fort Smith, AR 72901
782-8294

Coors of Western Arkansas
1900 Rogers
Fort Smith, AR 72901
783-9235

HARRISON

Joe Arnold Auto Salvage
Route 7 Box 34
Harrison, AR 72601
741-3581

HELENA

Centenio Distributing Co, Inc.
211 Missouri Street
Helena, AR 72342
338-6722

Budweiser Recycling for
the Handicapped
107 Walnut
Helena, AR 72342
338-8964

Stiles Iron & Metal Company
Old Little Rock Road
P.O. Box 2484
West Helena, AR 72390
572-5901

HOT SPRINGS

Abilities Unlimited
Mid-America Park
9 Centennial Drive
Hot Springs, AR 71913
767-8400

Dewey Cook Scrap Iron & Metal Co.
End of Gaines Avenue
Hot Springs, AR 71901
623-8901

Kizer Scrap Iron & Metal
Highway 5 & 7 North
Valley Street
Hot Springs, AR 71901
624-3275

Fraser Sales Company
150 Creek Street
Hot Springs, AR 71901
623-8201

JONESBORO

Hummelstein Iron & Metal Inc.
130 South Flint
Jonesboro, AR 72401
932-8361

LITTLE ROCK

ABC Salvage & Scrap Metals Co.
8116 Stagecoach Road
Little Rock, AR 72210
455-2225

Sol Alman Company
1300 East Ninth Street
Little Rock, AR 72202
375-5222

Blume Scrap Metals
1319 East Sixth Street
Little Rock, AR 72202
372-5864

Coca-Cola Bottling Co. of Ark.
Recycling Center
6901 Murray
Little Rock, AR 72209
569-2700

Coors of Arkansas
5300 Asher Avenue
Little Rock, AR 72204
563-9446

Reynolds Aluminum Recycling Co.
5201 Asher Avenue
Little Rock, AR 72204
562-7763

Benton Salvage of Little Rock
34th & Maple Street
P.O. Box 4047
Little Rock, AR 72214
661-1022

A-1 Aluminum Recycling Center
(aluminum cans only)
1300 East Ninth Street
Little Rock, AR 72202
372-5224

Ruff Iron & Metal Company
1700 East 15th Street
Little Rock, AR 72202
375-2309

Twin City Beverage Co., Inc.
1515 East Fourth Street
Little Rock, AR 72202
372-0185

P & H Distributing Co.
1900 East 15th Street
Little Rock, AR 72202
372-5168

MAGNOLIA

College Hill Scrap & Metal Co.
Route 1, Box 28 B
McNeil, AR 71752
695-3201

Southern Scrap Company
Hampton Road
Magnolia AR 71770
234-1194

Tillman's Scrap Metal Co.,
West Green Street
Magnolia, AR 71770
234-6573

McGEHEE

Delta Distributing Co., Inc.
300 Cypress Garden Street
McGehee, AR 71654
222-3989

MORRILTON

Otto Lienhart Inc.
Hwy 9 South at Airport 980
Morrilton, AR 72110
354-2282

John Gunderson Scrap Metals
100 South Cedar Street
Morrilton, AR 72110
354-8420

Morrilton Scrap Metal Yard
Hwy 9 Bypass on Sardis Road
Morrilton, AR 72110
354-1462

MOUNTAIN HOME

Carlson & Marotti
Reclamation Center
1229 Commerce Drive
Mountain Home, AR 72653
425-9878

NEWPORT

Jackson County Sheriff's Office
Second & Elm Streets
Newport, AR 72112
523-5842

NORTH LITTLE ROCK

Aluminum Recycling Corp.
Route 1, Box 47
Old Highway 70
North Little Rock, AR 72117
372-3944

Gray Supply Co. Inc.
13th & Marion Street
P.O. Box 961
North Little Rock, AR 72115
375-6491

Metal Recycling Corporation
Twin City Bank Bldg., Suite 740
P.O. Box 628
North Little Rock, AR 72114
374-9017

American Scrap Metal
1709 Jacksonville Hwy
North Little Rock, AR 72114
945-4830

Morris Scrap Metal
Old Conway Highway
North Little Rock, AR 72110
851-2013

PARAGOULD

Ed Roleson, Jr., Inc.
400 West Baldwin Street
Paragould, AR 72450
236-6150

Samuels Hide & Metal Co.
86 East Hunt Street
Paragould, AR 72450
236-6944

PINE BLUFF

Ace Battery Shop
2300 West Second Avenue
Pine Bluff, AR 71601
535-3363

M.K. Distributors, Inc.
223 Mulberry Street
Pine Bluff, AR 71611
534-0364

Soltz Machinery Shop
310 Tennessee Street
Pine Bluff, AR 71601
534-8522

Pine Bluff Junk Company
4525 West Barraque
Pine Bluff, AR 71601
534-7021

Southeastern Distributing Co.
2611 East Barraque Street
Pine Bluff, AR 71601
534-0460

Coors of Central Arkansas
Recycling Center
310 Texas Street
Pine Bluff, AR 71601
534-6223 also 1-800-482-5815

ROGERS

Arkansas Iron & Metal Co.
620 Nursery Road
Rogers, AR 72756
636-1722

A.C.E. Recycling
803 North Second
Rogers, AR 72756
636-0226

Rogers Iron & Metal Corp.
730 North Arkansas Street
Rogers, AR 72756
636-2666

RUSSELLVILLE

Cunningham Metals, Inc.
Hwy 7 South
Russellville, AR 72801
968-1574

Pope County Resource Recovery
Coalition
Route 3, Box 48
Russellville, AR 72801
293-4341 or 967-2981

SEARCY

The Thompson Co., Inc.
300 East Mulberry
Searcy, AR 72143
268-5626 or 268-1233

STUTTGART

Ludwig Distributing Co., Inc.
503 East 13th Street
Stuttgart, AR 72160
673-4482

SPRINGDALE

Cottrell's Scrap Metal Buyers
224 Caudle Street
Springdale, AR 72764
751-9571

TEXARKANA

Coors Recycling Center
700 East Broad Street
Texarkana, AR 75504
774-2795

Buchanan Distributing Co.
Stateline and Arkansas Blvd.
Texarkana, AR 75502
774-3883

JJS Distributing Co.
524 East Broad Street
Texarkana, AR 75502
774-4185

Tri-State Iron & Metal Co.
Hwy 67 North & East 14th Sts.
Texarkana, AR 75504
773-8409

Texarkana Iron & Metal Co.
721 East Broad
Texarkana, AR 75504
772-2132

WEST MEMPHIS

Coors of Eastern Arkansas, Inc.
211 North Sixth Street
West Memphis, AR 72301
735-0535

McCain Distributing Co.
One McCain Boulevard
West Memphis, AR 72301
735-0992

Mid South Iron & Metals
County Highway 520
West Memphis, AR 72301
732-6340

V.F.W. - Post 5225
406 South Avalon
West Memphis, AR 72301
735-9102

PAPER RECYCLERS

Individual centers offer different services to the public. Contact the recycling centers in your area to determine which one best suits your needs.

ASHDOWN

Enzorb Insulation, Inc.
Highway 71 South
Ashdown, AR 71822
898-5123

FAYETTEVILLE

Fayetteville Waste Paper Co.
Route 8 Box 276
Fayetteville, AR 72701
442-4772

FORT SMITH

Fort Smith Waste Paper Co.
112 North East Street
Fort Smith, AR 72901
783-6478

Resouroct, Incorporated
9709 Old Hwy 271 South
Fort Smith, AR 72906
646-8922

LITTLE ROCK

Goldman & Co., Inc.
1701 East 14th Street
Little Rock, AR 72202
376-7101

NORTH LITTLE ROCK

Paper Stock Dealers, Inc.
810 West Eighth Street
North Little Rock, AR 72114
376-4213

A. Tennenbaum Co., Inc.
4500 West Bethany Road
North Little Rock, AR 72117
945-0881

ROGERS

A.C.E. Recycling
803 North Second
Rogers, AR 72756
636-0226

RUSSELLVILLE

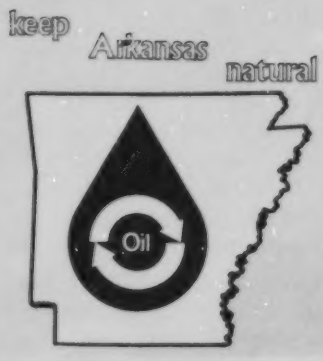
Pope County Resource
Recovery Coalition
Route 3, Box 48
Russellville, AR 72801
293-4341 or 967-2981

TEXARKANA

Muller Waste Paper & Rag Co.
107 Oak Street
P.O. Box 167
Texarkana, Texas 75501
(214) 794-5233

FOR A COMPLETE LISTING OF OIL RECYCLING CENTERS, CONTACT THE ARKANSAS ENERGY OFFICE.

Recycling Oil



Every year, more than 360 million gallons of valuable used motor oil are wasted by American car owners. This represents about 24,000 barrels a day that could be saved and re-used, instead of being imported into this country.

The Arkansas Energy Office has a Used-Oil Recycling Program to try and assure that used oil in Arkansas is recycled. This program has three purposes:

- to recover a valuable resource in Arkansas;
- to reduce environmental pollution caused by hazardous dumping of used oil;
- to save energy by recycling used oil.

The success of this program depends upon you.

So does the independence of this nation.

An immediate solution to our energy problem is to make the United States oil-independent. Today, a large percentage of our oil is imported. Due to our dependence on these foreign sources, we can no longer, as a nation, exercise self-determination as we have in the past.

Used motor oil is a neglected but valuable energy resource. It can help reduce our dependence on foreign oil by being put back to work as a lubricant or fuel.

This brochure tells how you can participate.

Recycling used oil back into clean lubricating oil takes only about half as much energy as refining the lubricant from crude oil.

To learn the name of the collection center in your town that will accept used oil call the Energy Hotline:

1-800-482-1122
or write:
Energy Office
One Capitol Mall
Little Rock, Arkansas 72201

RECYCLING OIL MAKES CENTS

Recycling Saves a Valuable Resource.

Every gallon of oil that is discarded is another gallon that must be purchased from a dwindling and ever more precious world supply. It takes 42 gallons of crude oil to produce 2½ quarts of motor oil. On the other hand, it only takes one gallon of used motor oil to make 2½ quarts of new motor oil.

The American Petroleum Institute estimates that there are eight million gallons of used oil generated every year in Arkansas. Approximately two million gallons are entering the oil recycling process annually.

Reduces Environmental Pollution.

The remaining six million gallons become a part of the problem. Used oils and their associated additives contain contaminants, which can cause pollution and health hazards. One

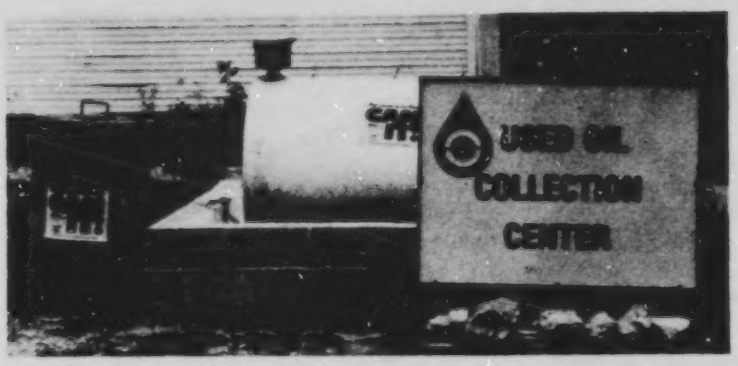
pint of oil will produce a slick up to an acre in size. Just one part oil per million parts water (1 ppm) can cause taste and odor problems in water. At 35 ppm, oil can produce a visible oil slick and damage aquatic life; 50 ppm can foul waste-water treatment processes.

In Arkansas, this six million gallons of used oil is currently being used for weed abatement, dust control and pest control on livestock, as well as being dumped openly into our environment.

By re-refining one gallon of used oil, we conserve the energy contained in the oil itself, about 149,000 BTU's (British Thermal Units). In addition, the process-energy required to refine the same amount of product, approximately 27,000 Btu's, is also saved.

This amounts to a savings of about 176,000 Btu's per gallon for each gallon of used oil which, through your efforts, reaches a local collection center.

Throwing used oil in with other household garbage risks pollution of the environment. Don't do it.



Dispose of used oil at a collection center such as this one, which serves Texarkana residents.

Be a part of
the used oil recovery cycle!

Recycle your used motor oil!

COLLECTION OF USED OIL

Currently, used crankcase oils are collected at service stations and fleet service-centers throughout the state. Used-oil hauling firms sump the oil into their tank trucks from the storage vessels, which may be located above or below ground. Typically, a 2,000-gallon-tank truck will service an urban area and return the oil to a bulk storage facility.

Larger semi-tanker trucks then haul the used oil to the processing facility or re-refinery, which may be located several hundred miles away.

If used oil is contaminated with large amounts of water, anti-freeze or solvents, the collection center may be required to pay the hauler.

On the other hand, if the oil is of a good quality as feedstock for a reprocessor or re-refiner, the hauler may pay the collection center on a per-galion basis. This figure is directly proportional to the demand for the used oil and the transportation costs.

The Arkansas Energy Office operates a toll-free referral service to inform the do-it-yourself oil changer about the location of the nearest used-oil collection center, so it will enter the cycle of used-oil recovery.

Used oil from your car, lawn mower, boat or farm equipment can be taken to the Sears or K-Mart auto service center nearest you.

Used oils from industrial facilities can also be recycled. For specific information, please contact the Arkansas Energy Office.

Used oil is not just waste to be handled; it also represents an opportunity for profit. Consider a used-oil collection operation for your organization — it has often been overlooked, but this could be a longterm fundraising project. The operation is neat and clean, despite the initial thought that such work might be messy or dirty.

CONSIDER THESE FACTS:

Oil never wears out . . . it just gets dirty.

Used oil once re-refined is just as good as, if not better than, new oil made from crude petroleum.

It costs less to re-refine used oil than it does to refine new oil.

About one out of three do-it-yourself oil changers have never heard about recycling oil.

About one out of five thinks that very little energy can be saved by recycling used motor oil.

Approximately six million gallons of used oil are dumped on the ground in Arkansas every year. A major portion of this oil can be recovered and recycled.

In the first months of an oil-recycling campaign, in early 1983, large numbers of Arkansas residents, business owners and civic-club leaders responded and many decided to participate in the oil recycling effort.

When a well-organized local organization informs community residents of a need for their help, people will donate time, money, merchandise and **used motor oil**. Your club, by offering a convenient means to dispose of used oil, can make some **slick, easy money**, month after month, year after year.

Call the Energy Hotline: **1-800-482-1122** to learn more.

USED OIL COLLECTION WILL WORK IN YOUR COMMUNITY.

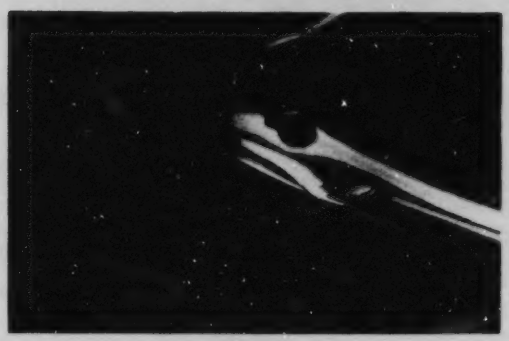
USED OIL COLLECTION WILL MAKE YOUR CLUB MONEY.

CHANGING YOUR OWN OIL

In these inflationary times, it is necessary to save money wherever possible. By following these steps, you can change your own oil with just an adjustable open-end wrench, filter wrench, can opener or oil spout and drain pan.

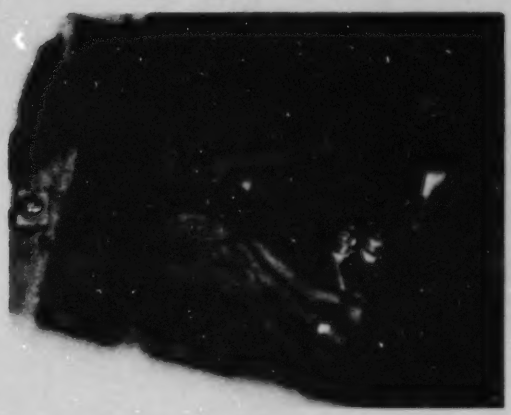
The job will go faster if the engine has been run recently, and is still warm.

1. Apply the parking brake and block the wheels.



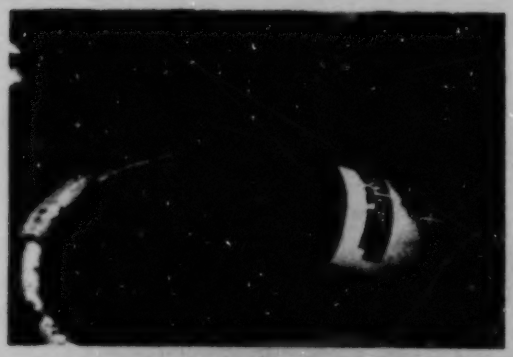
2. With the adjustable open-end wrench, remove the drain plug on the bottom of the oil pan; allow the oil to drain into the drain pan.

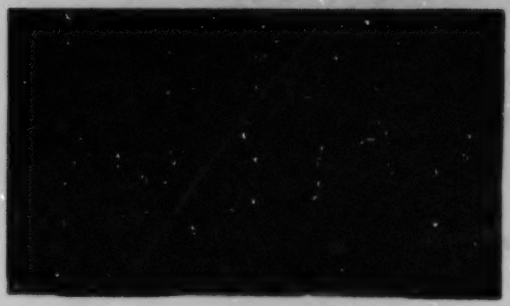
3. With the filter wrench, loosen the old filter and spin it off with your fingers; drain as much oil as you can out of the filter into the pan.



4. Dip your finger in the old oil and rub some on the rubber seal of the new filter; spin on the new filter;

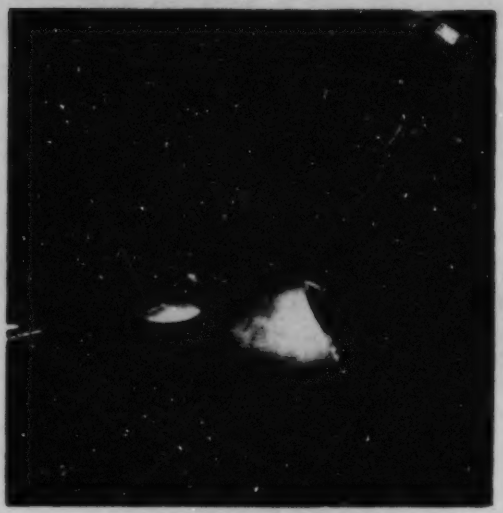
DO NOT USE A FILTER WRENCH. Tighten this snugly with your fingers.





5. Replace the oil pan plug; use the adjustable open-end wrench to tighten it securely.

6. Add the new oil. (Most cars use from four to five quarts; check your owner's manual).



7. Pour the used oil into a plastic container. RETURN USED OIL TO A COLLECTION CENTER.

Slick, Easy Money

DID YOU KNOW?

When disposed of improperly, used oil is not an asset but a very real threat to our environment.

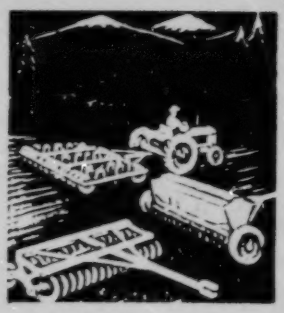
- Used oil is frequently a carrier of contaminants that are harmful to the environment.
- Crankcase oil drainings account for more than 40 percent of the total oil pollution of our nation's harbors and waterways.
- One pint of oil can produce an oil slick approximately one acre in size.
- One part of oil per million parts of water (1ppm) can cause taste and odor problems in drinking water. Thirty-five ppm can produce a visible oil slick on the water, which can damage aquatic life, and 50 ppm can foul a waste-water treatment process.

WHO GENERATES USED OIL IN ARKANSAS

Automobiles – 8,008,590 gallons per year.

Industry, aviation, and miscellaneous engines – 6,201,000 gallons per year.

Agriculture – 1,890,045 gallons per year.



ARKANSAS ENERGY OFFICE
Used-Oil Referral Service

TOLL-FREE
1-800-482-1122

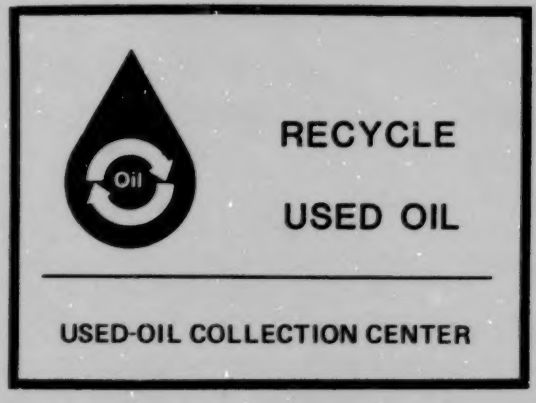
Arkansas needs your help!

Designate your business as a used-oil collection center.

Do-it-yourself oil changers and farmers in Arkansas need an environmentally-safe method of disposing of approximately seven million gallons of used oil each year. Collection centers can provide the method needed to accomplish this task.

WHY RECYCLE?

- Re-refined oil is just as good or better than oil refined from crude oil.
- Lubricating oil never wears out. . . it just gets dirty.
- It takes 42 gallons of crude oil to yield two-and-one-half quarts of lubricating oil provided by re-refining one gallon of used oil.
- Recycling used oil into clean lubricating oil takes only about half as much energy as refining it from crude oil.
- Arkansans throw away approximately seven million gallons of recoverable motor oil each year.
- If this oil was recycled, it would result in a savings of 170,300 barrels of oil per year that is currently being used to satisfy our lubricating oil needs.



ADVANTAGE$ OF BEING A COLLECTION CENTER

FINANCIAL PROFIT. Used-oil haulers will pay you for used oil that does not contain unusually-large amounts of water, fuel, anti-freeze, or other contaminants. The amount you receive for your used oil may vary. Used-oil prices effective in the spring of 1982 range from 18 to 24 cents per gallon.

LITTLE OR NO CAPITAL INVESTMENT. Used oil is generally donated to collection centers.

INCREASED FLOW OF TRAFFIC THROUGH YOUR BUSINESS.

ENHANCED PUBLIC IMAGE. You will be publicizing your interest in protecting the environment, conserving energy, and reducing dependency on foreign oil.

FREE ADVERTISING. Your business will be listed with the Arkansas Energy Office used-oil referral service.

SAFEGUARDS OF OPERATING A COLLECTION CENTER

Theft

As the price of used oil increases, the chance for theft also increases. For this reason, measures may be necessary to secure storage vessels while personnel are absent.

Identify Your Hauler

Personnel in your station should know who purchases your used oil. A good way to discourage unauthorized haulers from picking up oil at your facility is to post a note with the name, address and phone number of your hauler on your collection tank.

Short-Sticking

You should know how much oil you have when it is collected by the hauler. Otherwise, "short-sticking" can occur when the owner or employee of a collection center is unable to supervise pumping activities.

Beware of Unusually-Large Quantities

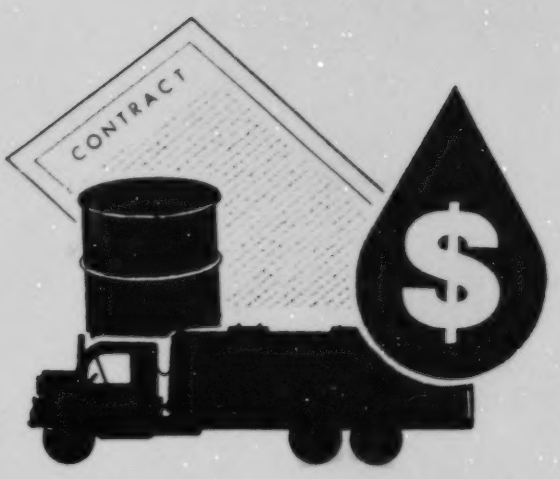
You should be extremely cautious when accepting quantities of used oil larger than five gallons from individuals. If quantities are larger than five gallons, you may be receiving oils contaminated with hazardous waste.

HOW TO BECOME A USED-OIL COLLECTION CENTER

- Obtain storage facilities for the used oil. (Fifty-five gallon barrels can serve as storage receptacles; also, some used-oil haulers furnish appropriate containers for temporary storage.)
- Notify the public that you are a collection center by:

A. Calling the Arkansas Energy Office to have the name and location of your business added to the statewide list of collection centers (Pulaski County: 371-1370; all other counties, toll-free: 1-800-482-1122).

B. Identifying yourself as a collection center with a large, clearly-visible sign. Signs are available for your use, upon request, from the Arkansas Energy Office. Please indicate your need for signs on the enclosed post card.



USED-OIL HAULERS

To become a used-oil hauler, you will need:

Hazardous-waste hauling permit from the Transportation Commission. (Required only if the used oil is being transported for purposes other than recycling.)

Contracts to purchase used oil from collection centers.

- Contracts to insure sale of used oil to a re-refinery.
- A 2,000-gallon tank truck to haul used oil from collection center to holding facility.
- A 10,000-gallon bulk storage facility.
- Your name and address listed with the Arkansas Energy Office used-oil referral service. (Call 371-1370 in Pulaski County or toll-free 1-800-482-1122 in all other counties.)

USED-OIL HAULING FIRMS

Carter Oil Service
6705 Old Jacksonville Highway
North Little Rock, Arkansas 72217
Phone: 945-7848

Oil Service Company
610 South Rock Street
Little Rock, Arkansas 72202
Phone: 378-3924

Oil Recovery, Inc.
P. O. Box 15003, GMF Station
503 East Sixth Street
Little Rock, Arkansas 72231
Phone: 372-0938

Taylor Waste Oil
6705 Old Jacksonville Highway
North Little Rock, Arkansas 72217
Phone: 945-2229

Ilada Energy
Cape Girardeau, Missouri
(314) 335-4280

DEFINITION OF TERMS

COLLECTION CENTER — Designated used-oil disposal location for do-it-yourself oil changers and agricultural oil users.

USED-OIL HAULER — Any person or persons controlling a system, or using mobile equipment, to transfer any type of used oil from the collection center to some other location, to facilitate recycling or disposal.

RECYCLING — The re-refining, reclaiming, or reprocessing of used oil to produce a material that can be used as a fuel or lubricant.

RE-REFINING — The use of petroleum refining techniques on used oil to produce lube stocks that are substantially equivalent in quality to lube stocks produced from virgin crudes. Techniques may include a combination of distillation, acid, caustic, solvent, hydrogen-treating, and other physical or chemical treatments.

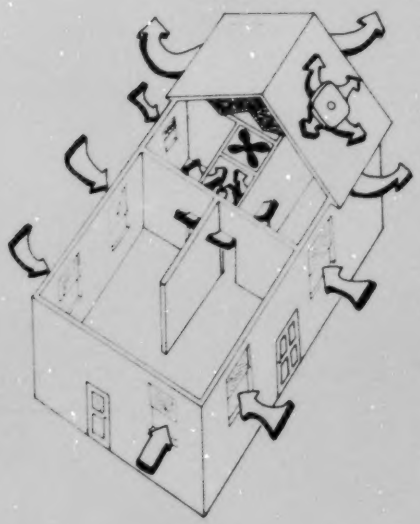
USED OIL — Any oil refined from crude petroleum oil or any re-refined oil which, through use or contamination, has become unsuitable for continued service in the applications for which it was originally intended. Specifically excluded from this definition are fuels, waxes, petrolatums, asphalts, and other petroleum products that are not generally considered to be "oils" or originally intended for use as a lubricant.

KEEPING COOL

Personal comfort is a matter of temperature, humidity, and air movement. Depending upon the humidity and the air-circulation patterns, it is possible to be more comfortable at 85 degrees than at 75 degrees. The greater the air circulation, and the lower the humidity, the more comfortable you will feel.

One way to accomplish this effect is to create a breeze. The best way to create a breeze is through the use of energy-efficient fans.

Fans have been around for many years. As cheap electricity became available, fans were gradually replaced with air-conditioning units that cooled an entire house.



These air-conditioning units consume vast amounts of electricity as they lower the indoor temperature and humidity. With the price of energy increasing almost daily, people are once again starting to look to the usage of fans for efficient, cheap, home cooling.

Everyone knows that when the sun goes down, so does the temperature. It is not abnormal to find as much as a 20 or 30-degree temperature shift between daylight and night, with the lowest temperatures attained just before sunrise.

The best way to use this natural cooling cycle is to circulate the night air through your home, cooling it until morning. As the outside temperature starts to rise, your home should be shut up, locking the cool air inside. A large window fan or whole-house fan in the attic can be used to draw in the cool air.

In the morning, turn off the fan, close the windows, and pull the drapes. In this way the cool air will be trapped inside your house and should keep your home cool until the evening hours, when once again you repeat the cycle.

To use fans effectively, there are some things you need to understand about moving air. Hot air tends to rise; therefore, the best circulation would occur using the downstairs windows to take in air and the second-story windows for exhausting the air to the outside. Placing a large fan in a second-story window or using a whole-house fan allows the hottest air to be drawn out of the house first, replacing it with the cooler outside air.

The best way to cool your house is to

install a whole-house fan. While attic fans are satisfactory as power ventilation equipment, whole-house fans are much larger, and are designed and installed so they improve air flow through the home. The first question people have concerning a whole house fan is: "What size?"

Whole-house fans are measured by their cubic-feet-per-minute (CFM) rating. Ideally, the rating of your fan should equal half of the cubic footage of your home. To find the cubic footage of your home, take the area of your home (length times width) and multiply that times the room height. The average room height is eight feet.

The sizing of whole-house fans is one of the more important things to consider. By buying a fan whose CFM equals half of your home's cubic footage, you will be, in effect, changing the air in your home once every two minutes, or 30 times an hour. This flow rate will ensure comfortable air movement throughout your home.

When using a whole-house fan, remember that the windows in the rooms furthest away from the fan should be opened the widest, with windows next to the fan opened the least.

In this way, a balanced air flow can be set up throughout your entire home.

Besides proper size, there are several other things a smart buyer will look for. First and most important is the Underwriters' Laboratories (U.L.) approval label. Since fans generally run all night long, it is important to buy a unit that is safe. A good thermal overload switch is an important part of that protection. Should anything go wrong, and the motor starts to overheat, the thermal overload protection will automatically cut off the power.

Another important part of a smooth-running fan is proper installation. Make sure the fan has the proper intake shutter and the proper exhaust-air outlets. A fan installed without proper exhaust-air outlets will not work efficiently, and will have a much shorter motor life. The increased back pressure could also cause serious overheating of the motor and other components.

Some other people prefer belt-driven fans as opposed to direct-drive fans. Generally, belt-driven fans are more quiet and more dependable, although they are slightly higher in price.

Another thing to consider is a solid-state speed control, or thermostat control. The speed control allows you to lower the fan speed, while the thermostat will turn the fan off at a predetermined temperature setting. These accessories can be purchased for about $30 each.

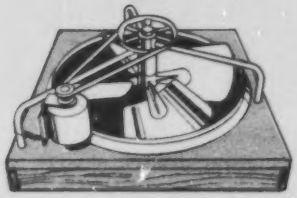
Fans Begin at $150

Whole-house fan prices run from $150 to $350 depending on size and construction. Ceiling shutters run from $50 to $150 depending on construction.

When purchasing shutters, a weather-stripped edge is important for ensuring energy savings year round!

When not using a whole-house fan, a smaller fan can still keep you cool. By circulating the air inside a closed room, you can produce the illusion of a cooler temperature, by increasing your body's evaporative cooling process.

Fans used in conjunction with air-conditioners will help to avoid stratification. An air-conditioned room with a fan can usually be kept 6 to 8 degrees warmer, and still maintain the same comfort level. Since fans do not actually lower the temperature, it is a good idea to turn off floor fans when not in use.



In a typical Arkansas home, a one-fourth to one-half horsepower (HP) whole-house fan costs about 2 cents an hour to operate. A three-ton central cooling unit costs about 31 cents an hour and a one-and-one-half ton window unit costs about 18 cents an hour. These figures are based on early 1983 electric rates.

Whole-house fan operating costs can be estimated from this equation:

$$\text{(Hours of Operation)} \times \left(\frac{\text{Fan Wattage}}{1000}\right) \times \text{(Power Cost*)} = \text{Cost of Operation}$$

*Current summer power cost for Arkansas is 7 cents per kilowatt hour.

Conservation Pays

When temperatures reach 100 degrees or more, as is common during Arkansas summers, many people turn to the air-conditioner to keep cool, but too much air-conditioning could result in monthly utility bills that are higher than the outdoor temperature.

It would seem that, as the throb of air-conditioners fills the night air, people have forgotten that there are other, more efficient, ways to keep cool in the summer heat. Even if you are one of those people who just could not live without air-conditioning, there are ways to use your air-conditioner wisely - saving you tremendous amounts of money on your summer cooling bills, while still maintaining a comfortable indoor temperature.

Cooling your home, like heating your home, costs money. Homes that waste your heating dollar will also waste your cooling dollar. Before turning on the air-conditioner for the summer, check these important items concerning your home's thermal condition:

- **Attic insulation** (Is there enough to reach the value of R-30?)
- **Caulking and Weatherstripping** (Is house airtight?)
- **Ductwork** (Is it properly insulated and sealed?)
- **Windows** (Tight-fitting and weatherstripped?)
- **Storm Windows** (Are these in place on windows that will not be used for natural ventilation?)

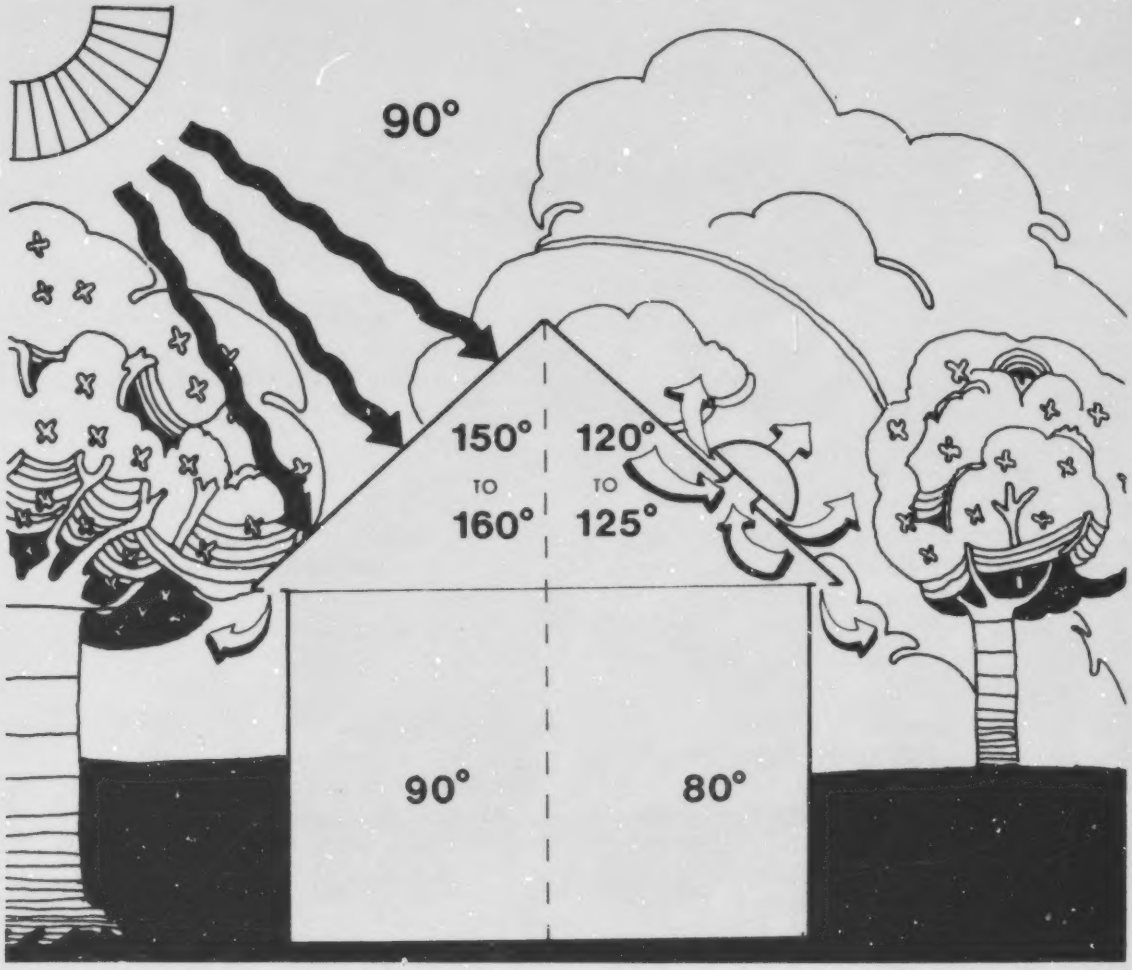
Once your home has passed this inspection and is thermally tight, check for other ways that heat enters your home during the summer. The biggest offender is the summer sun.

Screen Out Sunlight

The summer sun can quickly heat up rooms with east or west-facing windows. South-facing windows can also lead to increased heat gain inside your home. The easiest way to stop heat build-up inside your home is to stop the sun from shining in. Trees and shrubs are the best protection you can have from the summer sun. During the summer months trees and shrubs provide shade, keeping the summer sun out. In the winter, trees lose their leaves and allow the warming sun back into your home.

If trees are not available, solar screens or awnings can provide good protection from the sun. Keeping drapes closed on the east, south, and west sides of your home would be the next logical choice. Even solar reflective film will, to some degree, keep the sun out. The simple fact is, the more heat you can stop from entering your home, the cooler your house will be.

Attics have often been referred to as ceiling ovens. Every day the sun pounds down upon the roof of your home, causing the inside



of your attic to heat up. In Arkansas, it is not unusual for attics to reach 150–160 degrees under the heat of the mid-afternoon sun. Regardless of how well your attic is insulated, some of this heat will eventually find its way into your home, making it hotter, and more expensive to cool. Besides making you miserable, the heat also helps to shorten the life span of your roof.

In order to prevent this heat build-up in the summer, and moisture problems in the winter, it is necessary to have your attic properly ventilated.

Ventilation Cools Attics

Attics without power ventilating equipment need one square foot of unobstructed ventilation area for each 150 square feet of ceiling. Ridge or through-the-roof vents or louvers should provide 50 percent of this ventilation area in the upper part of the attic. Eave vents, or soffit vents, along the bottom edge of the roof, provide the remaining portion of ventilation and allow a smooth flow of air from the floor of the attic up through the peak of the roof.

Requirements for a ventilation area can be reduced to one square foot for every 300 square feet of ceiling, provided you have installed a proper vapor barrier. Power vents or wind turbines can be equally as effective in ventilating and cooling down your attic, provided they are properly placed and provide an adequate air flow.

Once your attic is properly ventilated to stop the ceiling oven effect, your home is weatherstripped and insulated to keep out the hot air, and your windows are protected from the sun's scorching rays, then you are ready to turn on the air-conditioner.

But wait, do you really need the air-conditioner?

Keep Solvent with Fans

If you find you still must use your air-conditioner, remember that you should set the temperature at the highest comfortable level.

At the present time, the setting of 78 degrees is suggested. For each degree below 78 on your thermostat, you will use 5 percent more energy. Keeping your home at 72 degrees will cost you 30 percent more than 78 degrees

If you are buying a room air-conditioner, remember to look for the Energy Efficiency Rating (EER). The EER is an effort to inform the consumer about the cost of electric appliances. The higher the EER, the more efficient the appliance, and the cheaper an air-conditioner is to operate.

Depending upon your lifestyle, a home with whole-house air-conditioning could save significant amounts of money by installing a small window unit in one or two heavy-usage rooms, and turning off the central system.

Summertime need not be a time of discomfort, either because of the temperature or utility bills.

Careful attention to the way you cool your home can result in significant savings.

For more information on how you can save energy and money call the Arkansas Energy Office toll-free at 1-800-482-1122.

ENERGY FACT SHEET

NATURAL COOLING

Before the advent of mechanical air conditioning, natural cooling techniques were applied in residential construction as a matter of course in the South. Use of natural cooling today can result in significant energy savings whether you are building a new home or renovating your present home. This Energy Fact Sheet describes natural cooling techniques that can help you reduce the need for air conditioning.

Natural cooling primarily functions to prevent a buildup of heat inside a home from solar gains and internal sources. The most common techniques employ ventilation and shading. Other techniques, which are currently being tried in many areas, involve using the earth or interior mass to cool a home.

VENTILATION

Throughout the South, outdoor conditions are very pleasant for a major portion of the year. During this time, good ventilation will increase comfort inside a building. Ventilation maintains inside temperatures near the outside levels and helps vent heat from solar gains and internal sources to the outside. In addition, the moving air makes higher temperatures feel cooler.

Cross Ventilation

Cross ventilation may be effective for most of the cooling season and can be used in place of air conditioning. When planning for natural cross ventilation, be aware that the direction of internal air flow does not always correspond to the wind direction. The wind creates areas of high and low pressure around a house. High pressure areas form where wind strikes the building and "backs up." Low pressure areas occur where velocities are high and eddies form on the down-wind side. Air moves into a building through openings in the high pressure regions and exits at low pressure areas.

Careful sizing and placement of air inlets and outlets can greatly enhance the cooling effect of cross ventilation. Generally, the inlets on the windward side of a home should be smaller than the outlets on the leeward side for maximum air velocity and optimum cooling *(see Figure 1)*. Also, inlets and outlets usually should not be placed directly opposite each other. This will only cool objects in the direct path of the air flow. A greater area will be cooled if the moving air has to change direction in the room.

Figure 1. Openings sized for maximum ventilation.

Another way to enhance natural cross ventilation is to shade air inlets, which will lower the temperature of incoming air. Also, you should minimize the amount of pavement in the wind's path. Concrete or asphalt driveways and patios absorb heat from the sun, raising the temperature of air coming in contact with these surfaces. Shading paved areas will reduce this unwanted heat gain, as will substituting materials such as grass, wood decking, white marble chips, and gravel.

Stack Effect Ventilation

Stack effect ventilation is primarily used to vent hot air that accumulates near the ceiling of a room. It operates on the principle that hot air rises and cold air descends (convection). Consequently, stack effect ventilation requires only that the inside of the house be warmer than the outdoors in order to drive the air flow. To achieve stack effect ventilation, there should be a large vertical separation between air inlets, located near the floor, and outlets close to the ceiling. Convection air flow is relatively weak, so this technique will not produce as strong a cooling effect as the more rapid air movement that can occur in cross ventilation.

Roof Ventilation

Good roof ventilation is essential for controlling heat gains through the ceiling. As a result of high sun angles, almost all roofs receive significant solar exposure during summer. The intensity of this solar radiation can drive unventilated roof and attic temperatures to 150°F, causing unwanted heat transfer through the ceilings and into the house. Good roof ventilation carries this heat out of the roof structure

or attic and prevents excessive temperature buildup.

Various types of roof vents are shown in Figure 2. Proper roof ventilation requires both an air inlet and an exit. Air inlets normally consist of vents at the roof soffits. Soffit vents should be generously sized and continuous.

Ridge vents and gable vents can serve as air outlets. These should be sized to provide an exit area equal to the inlet area at the soffit, and there must be a free flow path between the two. Air flow must not be obstructed by insulation or structural members. A combination of continuous soffit vents and ridge vents will move the greatest volume of air from the attic.

SHADING

The best way to reduce solar heat gains is to block the sun before it enters a building by shading windows with remote, external, or internal shading devices. East and west walls receive the most intense heat because of the lower altitude of the sun in the morning and afternoon. So, if you are building a new home, you should consider eliminating windows on east and west sides to substantially reduce summer solar heat gains in the house.

Remote shading employs objects which are not part of the building to provide shade. Trees, shrubs, vines, and walls can be used to block the low morning sun from east and west surfaces. Shading south-facing windows can best be accomplished by using deciduous trees which block the summer sun but shed their leaves to admit sunlight in winter. North walls can also receive sunlight, but in most cases this has minimal impact on summer heat gain.

Shading the roof is a very important method of reducing heat gains. A good strategy is to locate the house close to or beneath existing large deciduous trees so that their canopies extend over the roof. Also, a light colored roof will reflect solar radiation that would be absorbed by a dark colored roof.

The use of exterior and interior shading devices is also a good way to block the summer sun. Exterior shading devices can prevent up to 95 percent of the sun's heat from reaching the interior of a home. Overhangs, trellises, shutters, awnings, porches, and carports are examples of exterior shades which are part of a building. Modest fixed overhangs are effective in blocking direct solar radiation from entering south-facing windows. Since diffuse and reflected solar radiation may account for a significant portion of the energy reaching an unshaded south window, additional forms of shading, such as blinds or shades, are required. Very wide overhangs, such as carports, porches or awnings, are effective in reducing solar heat gains from windows of any orientation. However, it is important to provide ventilation at the top of awnings or similiar devices so that a build up of excessively hot air does not add to the heat load by means of simple conduction. Several types of movable weather-proof exterior shades and blinds are also available for exterior shading.

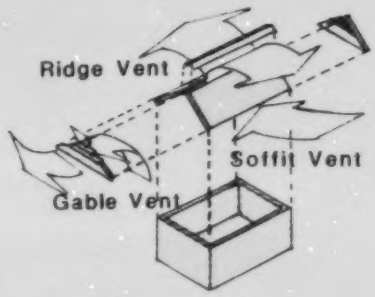


Figure 2. Roof vents.

Interior shades provide an easily controlled last line of defense against unwanted solar gains. Blinds, shades, and drapes will reflect 20 to 50 percent of the sun's radiant energy back through the glass. Performance improves with opaque materials, lighter colors, reflective backings, and shades that fit close to the glass. Interior shading is not as effective as exterior shading since some of the energy escapes into the house instead of being reflected back to the outside. So for best results, use interior shades in conjunction with an exterior device.

OTHER TECHNIQUES

Using the earth or interior mass for natural cooling has become a popular concept recently. While such techniques have not yet been thoroughly tested or measured, many who have used them believe them to be effective.

Underground houses and earth berming are examples of using the earth's mass to enhance cooling. The ground is typically cooler than hot summer air and hence will reduce the heat gains through a home's walls. In many locations, the ground is cool enough for heat to flow from the building to the ground. This actually cools the building rather than simply reducing heat gains. However, condensation on earth cooled walls can be a problem in humid areas. Another earth cooling technique employs underground tubes through which air is drawn before it enters the building. Length, depth, and diameter of the tube, soil properties, and climate are critical factors in determining how effective earth cooling tubes will be.

Interior mass may also be used for natural cooling when the nighttime temperature is 25 degrees or more cooler than the temperature during the day. The mass may be interior masonry walls or floors, a brick fireplace, or containers of water. At night, windows are opened and the mass is cooled by natural or forced ventilation. During the day, the house is closed up and the mass absorbs heat, lowering the temperature of the inside air. To function effectively as a natural cooling technique, the mass should not be exposed to direct sunlight during the day.

Natural cooling techniques are regaining popularity in the South because of rising energy costs. These techniques can both reduce the total cooling energy used and shorten the time during the year when air conditioning is required. However, they will have little affect on high humidity levels, which can best be reduced by using conventional air conditioning. Also, to use natural cooling techniques effectively, you should first employ good energy conservation practices. Measures taken to reduce energy use year round, such as turning off unnecessary lights and appliances, caulking, weatherstripping, and insulating walls and ceilings, will also reduce unwanted internal heat gains that cause discomfort during the summer.

ENERGY FACT SHEET

INSULATION AND COOLING

Most conservation practices that decrease a home's heating needs, such as caulking, weatherstripping, and insulating, also reduce energy consumed for cooling. This Energy Fact Sheet illustrates how insulation levels affect a home's cooling requirements and provides a means of calculating the savings in cooling costs that can result from adding insulation to your home.

A good way to reduce air conditioning costs without increasing discomfort is to reduce a home's cooling requirements – its cooling load. The cooling load for a house can be separated into the individual cooling loads for roofs, walls, and floors. The graphs in Figures 1 through 5 illustrate the effect of increased insulation on reducing the cooling load for these structural areas. The cooling load is shown as the "cooling load coefficient" – a lower cooling load coefficient means a lower cooling load.

Use of the figures to determine the change in a home's cooling load from increasing insulation levels is best illustrated by an example. Consider a 1,500 square-foot home in Jackson, Mississippi, with a dark roof and R-10 insulation in the ceiling. The homeowner is considering increasing the ceiling insulation to either R-19 or R-30.

Figure 1 has the lines drawn to illustrate the example. Jackson has a design temperature of 95°F. (The design temperature, which is used in sizing a home's air conditioner, is shown for various cities in Table 1.) A line is drawn from the appropriate R-value on the vertical axis to the 95° design temperature curve, and then a line is drawn down to the horizontal axis from the 95° curve. The point where the line intersects the horizontal axis is the cooling load coefficient for the appropriate R-value. The cooling load coefficients for R-10, R-19, and R-30 insulation values are 4.4, 2.3, and 1.5, respectively.

Table 1. Cooling Design Temperatures and Full Load Cooling Hours (FLCH)

Location	Design Temp.[1]	FLCH[2]	Location	Design Temp.[1]	FLCH[2]	Location	Design Temp.[1]	FLCH[2]
Amarillo, Tex.	95	1340	Greenville/			Nashville, Tenn.	94	1440
Asheville, N.C.	87	1220	Spartanburg, S.C.	91	1420	New Orleans, La.	92	2440
Atlanta, Ga.	92	1520	Houston, Tex.	95	2440	Norfolk, Va.	91	1330
Augusta, Ga.	95	1770	Huntington, W. Va.	91	1130	Oklahoma City, Okla.	97	1510
Baltimore, Md.	89	1170	Huntsville, Ala.	93	1560	Orlando, Fla.	93	2650
Baton Rouge, La.	93	2250	Jackson, Miss.	95	1910	Paducah, Ky.	95	1510
Birmingham, Ala.	94	1740	Jacksonville, Fla.	94	1850	Raleigh/Durham, N.C.	92	1430
Charleston, S.C.	92	1850	Lexington, Ky.	91	1200	Richmond, Va.	92	1310
Charleston, W. Va.	90	1200	Little Rock, Ark.	96	1770	Roanoke, Va.	91	1200
Charlotte, N.C.	93	1460	Louisville, Ky.	93	1390	Salisbury, Md.	91	1140
Chattanooga, Tenn.	93	1500	Memphis, Tenn.	95	1690	San Antonio, Tex.	97	2380
Columbia, S.C.	95	1720	Meridian, Miss.	95	1900	Shreveport, La.	96	1950
Corpus Christi, Tex.	94	2950	Miami, Fla.	90	3820	Tulsa, Okla.	98	1600
Dallas, Tex.	100	2210	Mobile, Ala.	93	2110	Valdosta, Ga.	94	2050
Fayetteville, Ark.	94	1600	Morgantown, W. Va.	87	820	Washington, D.C.	91	1250
						Wilmington, Del.	89	1030

[1] Source: *ASHRAE Handbook 1981 Fundamentals*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. The design temperature as shown here is the 2.5% design temperature, which means that for 97.5% of the time the outside temperature will be below the design temperature.

[2] Source: *Insulation Manual – Homes and Apartments*, National Association of Home Builders, 1980. All full load cooling hours have been increased by a factor of 30% to reflect the latent loads typical of the southern region.

HOW TO CALCULATE SAVINGS

Cooling cost savings can be determined by the following equation:

$$\$ \text{ Savings} = \frac{(\triangle \text{ CLC}) (\text{Area}) (\$/\text{kWh}) (\text{FLCH})}{(\text{EER}) (1000)}$$

△ CLC = Change in cooling load coefficient from one R-value to another

Area = Total square-foot area where insulation is to be applied

$/kWh = Electricity Rate

FLCH = Full load cooling hours

EER = Energy efficiency ratio of air conditioner

In the example, the ceiling area is 1,500 square feet and the current cost of electricity is $0.06/kWh. The FLCH (full load cooling hours) is a measure of the number of hours the air conditioner will operate given typical weather conditions for a particular location. The FLCH for various cities is shown in Table 1. The FLCH for the Jackson area is 1,910. The example assumes an air conditioner with an EER of 8. The seasonal EER is required to be displayed on all air conditioning equipment and is calculated by the American Refrigeration Institute.

Increasing the insulation from R-10 to R-19 in our example causes a change in CLC of 2.1. The resulting cooling cost savings can be calculated as follows:

$$\$ \text{ Savings} = \frac{(2.1) (1,500) (0.06) (1,910)}{(8) (1,000)} = \$45.12$$

The cooling load coefficient change from R-10 to R-30 is 2.9, and the savings will be:

$$\$ \text{ Savings} = \frac{(2.9) (1,500) (0.06) (1,910)}{(8) (1,000)} = \$62.31$$

This means that the homeowner in Jackson, Mississippi, will save $45.12 a year in cooling costs alone by increasing the ceiling insulation in his home from R-10 to R-19. Adding even more insulation to achieve an R-30 level will result in an annual savings of $62.31, or about $17 more than the R-19 level.

RELATIVE ECONOMICS

Insulation effectively reduces the cooling load for a home, but a point of diminishing return is reached when the expense of increasing insulation is not returned in cooling cost savings. In order to determine this point, the actual costs of insulation and electricity should be used to calculate the net benefits or costs.

In general, an examination of the curves in Figures 1 through 5 can provide a fair representation of the value of increasing insulation for cooling load reduction. Flat sections of a curve show large reductions in cooling load for small increases in insulation, while steep curves mean only small reductions in cooling load for large increases in insulation. The flatter curve sections mean more cooling cost savings per investment in insulation than the steeper curve sections. For example, compare Figures 1 and 5. Notice how in Figure 1 small increases in R-value, from R-5 to R-15, result in significant reduction in the cooling load coefficient. But when the R-value exceeds R-20, the curve steepens, and very little reduction in cooling load occurs for increasing insulation levels above R-20. In Figure 5, the curves become steep at a lower R-value, around R-10. Consequently, increasing insulation in the ceilings of homes with dark roofs would be more beneficial than increasing insulation in the floors.

When applying these calculations to determine optimum insulation levels, remember that insulation will also affect heating bills. In fact, in many areas the heating cost reduction will be the largest contribution to cost savings. Information on the impact of insulation on a home's heating needs may be obtained from utilities, insulation manufacturers, and heating system installers.

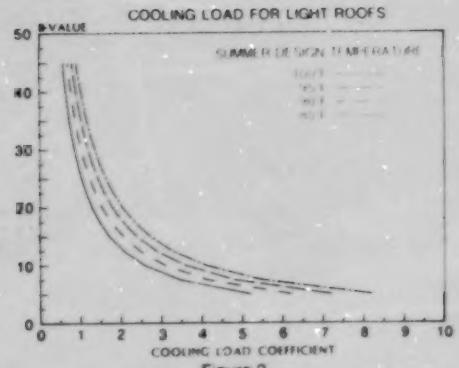


Figure 2.

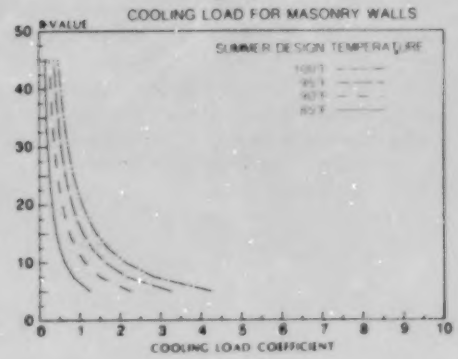


Figure 3.

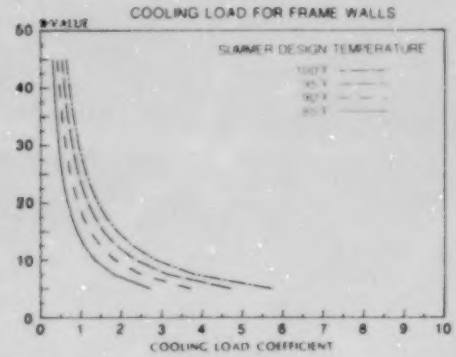


Figure 4

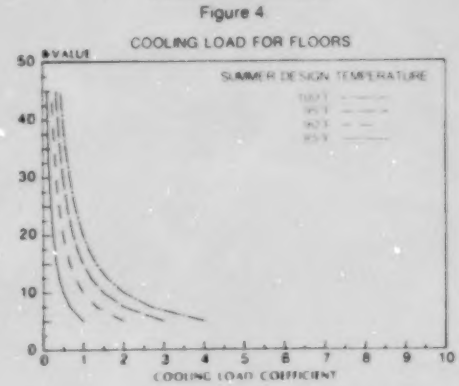


Figure 5

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ENERGY FACT SHEET

MOVABLE INSULATION

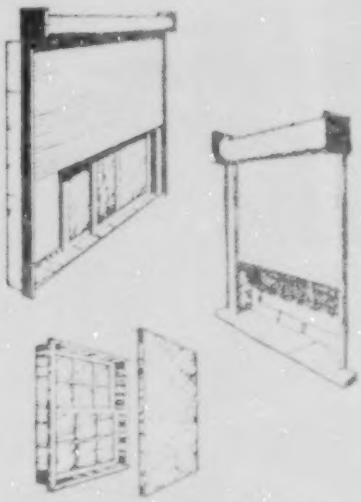
"Movable insulation" refers to a variety of products and techniques used in homes to reduce heat losses through windows in the winter. A conventional home can lose from 20 to 50 percent of its heat through the windows. Passive solar homes with large amounts of glass are particularly vulnerable to nighttime heat loss through the windows in the winter. The techniques described in this Energy Fact Sheet can cut window heat losses in half.

REDUCING HEAT LOSSES

There are several ways in which heat loss can occur with a window. These include conduction, convection, radiation, and infiltration. Conduction is heat transfer through solid objects such as the window pane and sash. Convection is heat transfer through moving gases and is often the driving force which causes slow but continuous air movement where heat is lost to the pane. Radiation is heat transfer within the electromagnetic spectrum. One example is radiant heat from a fireplace or the sun. Another example is radiant heat loss to the night sky which represents the cold of outer space. Infiltration is simple heat loss by air movement through the seals around the sash or cracks and other openings where the window attaches to the wall.

Effective movable insulation should be designed to reduce all types of heat loss. It should have an insulating material or dead air space to reduce conductive heat loss. Radiation heat loss can be reduced through the use of an opaque material. Any opaque material will serve as a radiation shield; however, a reflective surface, such as dense aluminized mylar, may be useful if it is desired to reflect interior heat. Proper installation with a good fit and tight air seal is necessary to reduce convective heat losses and infiltration.

The effectiveness of movable insulation in reducing heat losses depends on several factors, including the R-value of the movable insulation product. One study looked at daily heat losses through one square foot of glass on a winter day with a 30°F average outdoor temperature and a 65°F average indoor temperature, using movable insulation of various R-values for 14 hours a day (1). It found that the greatest reductions in heat loss occurred in the low range, up to R-4 insulation. The study showed that single glazing with R-4 insulation was equivalent to double glazing, saving about 50% of the heat loss that would occur with uninsulated single glazing. Double glazing with R-4 insulation resulted in savings of around 40% as compared to uninsulated double glazing. Insulation ranging from R-4 to R-8 caused further heat loss reductions, but these reductions were relatively small. Above R-8 very little additional savings were achieved because as long as the windows are left uncovered for 10 hours during the daytime, the heat loss reduction can not exceed about 58%.



Different materials will have different R-values. As an example, a one-inch layer of polystyrene bead board or a three-inch air space will have an R-4 value. Most commercially available movable insulation products will specify their R-value.

INTERIOR MOVABLE INSULATION

Movable insulation inside the house is the most common type of product. Interior movable insulation has advantages over exterior forms since it is protected from weather elements and can be simpler and easier to operate. Also, interior insulation does not interfere with the exterior appearance of the home. A disadvantage can be the problem of moisture condensation between the insulation and the window. Other disadvantages include alterations to the interior appearance of a room and interference with furniture and living space, depending on the size and type of interior movable insulation. The following descriptions illustrate some of the more common forms of interior movable insulation.

Thermal Curtains and Shades — Conventional curtains and "thermal" liners in use in most homes have little if any insulating value. They are primarily decorative pieces. To be

an effective form of insulation, thermal curtains and shades must seal tightly to the window frame to prevent convective losses. The material should also be resistant to the deteriorating effects of sunlight, heat, and moisture. Thermal curtains are drawn and folded like typical curtains and drapes, while thermal shades are rolled up or down over the window opening (see Figure 1).

Thermal Shutters — Interior thermal shutters vary according to the materials used and the means for fitting them in the window. Appropriate materials are foam isocyanurate sheathing, polystyrene, or polyurethane foam sheathings, which are usually encased in wood, metal, or plastic for strength. Methods for preventing convective losses depend on how the thermal shutter is installed. It can be a pop-in type with either a glass-hugging, edge-seal, or friction-fit shutter (see Figure 1). Side-hinged and top-hinged shutters can be easier to use than the removable pop-in types since they do not have to be stored during the day, but they use more interior space. Other types include interior sliding shutters which slide next to the window when not in use and pocket shutters which slide into the walls when retracted.

Between the Glazings — Certain types of windows can accommodate innovative strategies that involve insulating the space between the glass panes. Various methods involve using styrofoam beads, shades, louvres, or blinds between the window glazings (see Figure 2). However, moisture condensation between glass panes can be aggravated by the connections to the extra mechanical parts required with these systems. These systems are also more costly because of their increased complexity.

Skylights and Clerestories Insulation — Skylights and clerestories are often used for passive solar heating and natural lighting, but are usually subject to greater heat losses than normal windows. Movable insulation is very valuable for these types of windows. Sliding, louvered, and hinged shutters can be employed to reduce heat loss through skylights. An example of louvered skylight insulation is shown in Figure 2. Top-hinged, bottom-hinged, and sliding shutters are often used for clerestories. The high heat loss from skylights and clerestories can justify more expensive movable insulation as compared to systems for conventional windows.

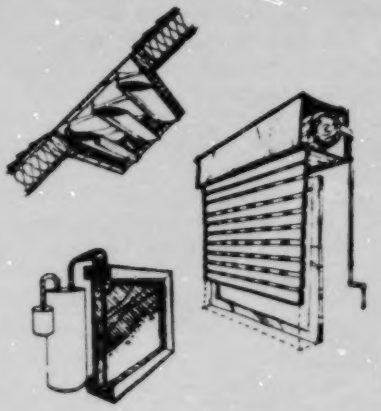


Figure 2. Temperature-sensitive skylight louvers, an exterior roll shutter that can be operated from the interior, and a mechanically-operated bead wall that is filled with foam beads at night.

EXTERIOR MOVABLE INSULATION

Advantages of exterior movable insulation are that moisture condensation is not a problem, the systems do not take up any interior living space, and they can be designed to reflect sunlight into the house for additional solar heat gain during the day. Exterior systems can also provide security value and better summer sun protection than interior types. Disadvantages include their constant exposure to the elements and the fact that exterior systems are usually more expensive because of their operating controls. The more common systems involve shutters.

Exterior Hinged and Sliding Shutters — Exterior shutters can be installed with hinges and swing into place or installed on a track mechanism to slide into place. Exterior hinged shutters can be used to reflect sunlight into the home during the day as well as reduce heat loss at night if they are painted white or coated with a reflective material like anodized aluminum.

Exterior Roll Shutters — These systems are generally either a roll down shutter or an apparatus similar to an overhead garage door. The roll type shutter is made of narrow slats that are wound onto a cylinder at the top of a window (see Figure 2). The garage door shutter operates similarly but can be designed to match the siding of the rest of the house so that it presents a uniform exterior when the door is closed.

Just as they prevent heat loss during the winter, movable insulation systems can also block unwanted heat gain in the summer. They can be very effective for this purpose, especially when used in conjunction with other shading devices such as awnings, overhangs, and shade trees.

In terms of currently available movable insulation, interior roll down window quilts and thermal curtains are most popular. Interior shutters are the next most common, followed by roll down exterior shutters. The use of movable insulation should continue to gain popularity as homeowners look for ways to reduce the heat escaping from their home during winter.

REFERENCES

1. Langdon, William K. *Movable Insulation*. Emmaus, PA: Rodale Press, 1980.

2. Adams, Jennifer K., "What to Look For in Window Insulation," *Solar Age*, January, 1982, pp 46-48.

TECHNICAL BRIEF

VENTILATION

For a major portion of the spring and summer, outdoor temperatures in the South are below 84°F. Even during the summer such temperatures occur almost always in the evening and often during the daytime. Under these conditions, good ventilation can keep the inside of a home comfortable without the aid of air conditioning. Interior ventilation maintains inside temperatures near outside levels and serves to prevent a buildup of heat from solar gains and internal sources. Roof ventilation controls intense summer heat gains through the ceiling of a house, which helps decrease the need for air conditioning as well as reduce the cooling load when air conditioning is required. This Technical Brief describes various ventilation techniques.

INTERIOR VENTILATION

In many areas a combination of natural and forced ventilation can increase interior comfort levels and substantially reduce the need for air conditioning. When the outdoor temperature is between 65 and 84 degrees, a home can be effectively cooled solely by ventilation. Generally, natural ventilation may be adequate when the temperature is 65 to 74 degrees, and forced ventilation (ventilation using fans) becomes necessary with temperatures ranging from 75 to 84 degrees. Table 1 shows the number of hours that the outdoor temperature falls within the 65 to 74 and 75 to 84 degree temperature range for various locations. These figures represent the *potential* number of hours that a home can be cooled solely by ventilation. The data, however, does not account for humidity or sunshine. With high humidity or bright sunshine, air conditioning may be required even when the temperature falls below 84 degrees.

Natural Ventilation

Natural ventilation may be driven by winds (cross ventilation) or by thermal forces (stack effect ventilation). Cross ventilation is caused by the wind, but it is not literally wind flowing through the building. The wind creates areas of high and low pressure around a house. High pressure areas form where wind strikes the building and "backs up." Low pressure areas and eddies occur on the down-wind side. Air moves into the building through openings in the high pressure regions and exits at low pressure areas; thus the direction of internal flow does not always correspond to the wind direction.

The placement and sizing of air inlets and outlets can enhance cross ventilation in a house. Better ventilation will occur when windows are located on opposite or adjacent walls rather than only on one wall. Also, a greater area will be cooled if the air flow has to change direction in the room. For this to occur, inlets and outlets should not be located directly opposite each other (See Figure 1).

The inlet window location will be the primary influence on room air flow. Moving air that flows near a surface attaches to that surface. So, if the inlet window is located near the ceiling, then the air will

Table 1. Frequency of Outdoor Temperatures Suitable for Ventilation
May — October

Location	HOURS 65-74°	HOURS 75-84°	HOURS Above 84°	Percent of Total Hours over 65° When Ventilation Cooling is Possible
Atlanta, Ga.	1,749	1,346	521	86%
Austin, Tex.	1,043	1,754	1,236	69%
Baltimore, Md.	1,615	1,013	314	89%
Birmingham, Ala.	1,391	1,425	776	78%
Campbell, Ky.	1,559	1,175	485	85%
Charleston, W. Va.	1,534	985	324	87%
Dover, Del.	1,582	1,017	263	91%
Greensboro, N.C.	1,675	1,068	414	87%
Greenville/ Spartanburg, S.C.	1,731	1,241	498	86%
Jackson, Miss.	1,399	1,500	966	75%
Jacksonville, Fla.	1,624	1,645	836	80%
Knoxville, Tenn.	1,626	1,274	505	85%
Little Rock, Ark.	1,375	1,475	772	79%
New Orleans, La.	1,184	2,193	717	83%
Oklahoma City, Okla.	1,387	1,339	647	81%
Richmond, Va.	1,523	1,071	499	84%

Source: Departments of the Air Force, the Army, and the Navy. *Facility Design and Planning: Engineering Weather Data*, U.S. Government Printing Office, 1978.

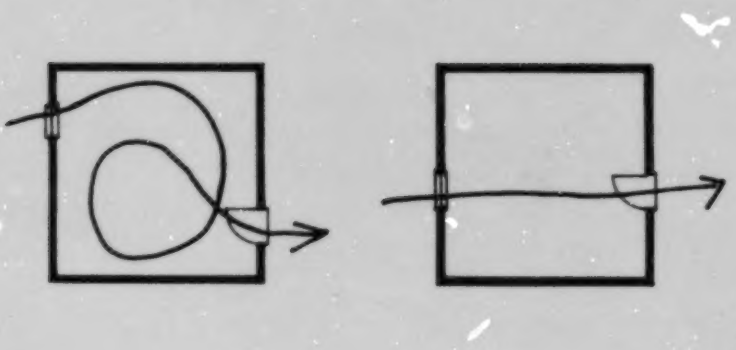


Figure 1. A greater area will be cooled if air flow changes direction between inlet and outlet.

flow across the top of the room. On the other hand, inlet windows near the floor will direct the air across the floor area (See Figure 2). Usually low inlet window placement will cool people and objects in a room better because the moving air will flow directly over and around them. The placement of the outlet window, in terms of height, will have little effect on the air movement through a room.

If the direction of the wind changes frequently, equal inlet and outlet areas are recommended for best ventilation results. However, if the wind flows primarily in one direction, then an outlet area that is larger than the inlet area will increase the velocity of the air flow within the room, thereby enhancing the cooling benefit.

Landscaping can also increase the usefulness of outside air for natural ventilation. Shading air inlets will lower the temperature of incoming air. Air under a shade tree can be 10 to 20 degrees cooler when the general temperature is 90°F, and 5 to 10 degrees cooler when the general temperature is 70°F. When shading air inlets, however, care must be taken to avoid obstructing the flow of air through the house. In addition, proper landscaping can be used to channel the air flow and increase the effective ventilation.

Another way to keep incoming air as cool as possible is to minimize the amount of pavement in the wind's path. Concrete or asphalt driveways and patios absorb heat from the sun, raising the temperature of air coming in contact with these surfaces. Shading paved areas will reduce their heat contribution to breezes that create cross ventilation within a home.

Stack effect ventilation is a natural ventilation technique that uses thermal forces to drive the air flow. To employ this technique, a room should have outlets located at the top of the room near the ceiling and inlets near the floor. Stack effect ventilation requires only that the inside of the house be warmer than the outdoors in order to drive the air flow. The temperature difference between warmer indoor air and cooler outdoor air will cause a stack effect (See Figure 3). Greater air flow will be induced with large vent openings and a long vertical separation between inlets and outlets. Stronger air flow will also be created when there is a great difference between indoor and outdoor temperatures. However, this condition, which requires that the building's interior be substantially hotter than the outdoor temperature, may be uncomfortable for occupants. So, stack effect ventilation should not be the only, or even the primary, cooling technique employed in a home.

Forced Ventilation

Forced ventilation relies on fans to move air rapidly. This rapid air movement will make warm temperatures feel cooler. In cold weather, the effect of moving air on the temperature is called the "wind chill factor."

There are two kinds of fans commonly used in residences today – ceiling fans and whole-house fans. Each functions differently in cooling a home.

Ceiling fans move the air in individual rooms to cool occupants. They can also be used in conjunction with air conditioning. With the cooling effect of rapid air movement, the thermostat setting for the air conditioner can be raised without causing discomfort. This increase in the thermostat setting can result in significant cooling cost savings. The amount of savings will depend on geographic location, climate, the cost of energy, and the residents' energy-use habits.

The volume of air a ceiling fan can circulate is measured in cubic feet per minute (CFM). This rating, which is approved by the National Electrical Manufacturers Association, is used in sizing a fan for a particular room. To select a ceiling fan of the right size, first measure the length and width of the room where the fan will be installed. Next, multiply these factors to determine the area of the room in square feet. Approximately 55 CFM of fan capacity is required for each square foot of room area. For example, a 12 foot x 10 foot room has an area of 120 square feet. This room requires a ceiling fan with a rating of 6,600 CFM (55 x 120) for good ventilation results.

Before installing a ceiling fan, the height of the ceiling and the fan should be carefully measured. A clearance of at least 7 feet below the fan is recommended.

Whole-house fans, sometimes called attic fans, are used in place of air conditioning when outside temperatures and humidity levels are reasonable. A whole-house fan should only be used when the outdoor temperature is cooler than the temperature inside. Consequently, it can be an especially effective cooling technique at night. A whole-house fan system consists of a large propeller fan usually mounted in the attic above a ceiling opening in a central part of the house. The fan draws air through open windows, pulls it throughout the home and into the attic, where it is expelled out the vents.

Ceiling shutters with insulated vanes should be installed below the fan to close the opening when it is not operating. The fan can be controlled automatically by a timer or a thermostat. It is recommend-

ed that a panel with additional insulation be installed below the ceiling shutters during the winter months to minimize heat loss. This panel should employ a seal to prevent air leaks. While such panels are not generally available commercially, they can be easily fabricated for most ceiling openings.

Although whole-house fans can be an effective means of cooling and ventilating a home, there is no good way to control humidity and air movement while the system is operating. When relative humidity levels are high, air conditioning may be required even though the ambient temperature may be low enough for ventilation cooling. Also, a serious safety hazard would exist if the fan were to continue operating during a fire. For this reason, the system should incorporate a smoke detector or other fire-sensing device.

The first step in sizing a whole-house fan is to determine the volume of each space to be ventilated – multiply length x width x height. Closets, storage rooms, or the attic should not be included. The total room volume determines the total space to be ventilated in cubic feet. For best cooling results, the fan should have a CFM equal to the cubic feet to be ventilated. For example, a 1,200 square foot home with 8 foot ceilings will need a whole-house fan with 9,600 CFM (8 x 1,200) capacity.

Exhaust vents in the attic for a whole-house fan should be sized to provide one square foot of unobstructed vent area per 750 CFM of fan capacity. Consequently, in the example house, total free vent area in the attic should be about 13 square feet.

Window fans can also be used as whole-house fans. An outward blowing fan serves as an exhaust fan which forces hot inside air to the outside and pulls in cooler air through open doors and windows elsewhere in the house. A window fan used in the exhaust mode should be placed on the side of the house away from the wind or in an upstairs window. A window fan facing inward can serve to bring in cooler outside air at one central location, forcing hot inside air out several windows or doors. For best results, the air intake fan should be placed in a window that is shaded.

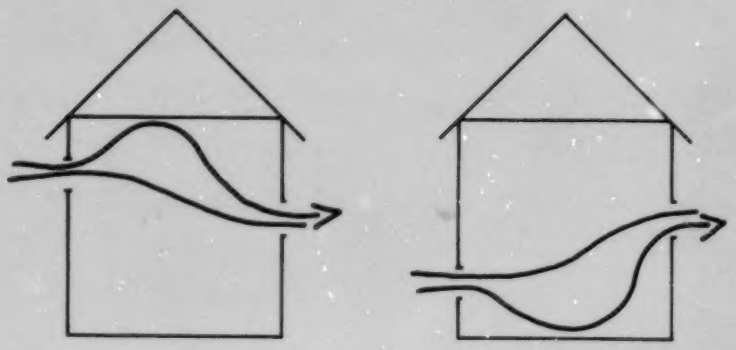


Figure 2. Air moving near a floor or ceiling will attach to that surface.

ROOF VENTILATION

As a result of high sun angles, almost all residential roofs receive significant solar exposure during summer. The intense solar radiation can drive poorly ventilated roof and attic temperatures above 140°F, causing unwanted heat transfer through the ceilings and into the house unless the ceilings are well-insulated. Good ventilation carries solar heat out of the roof structure or attic and prevents excessive temperature build-up. The result is lower cooling costs, greater comfort, and longer roof shingle life. If a home's ceiling is well-insulated (R-19 or more), roof ventilation will have little effect on cooling costs since little of the heat from the attic will penetrate to the home's interior. However, roof ventilation is still important for preserving roof shingles and for using the attic as a storage space for items that can be harmed by excessive heat.

A second function of roof ventilation is the removal of moisture during the winter. Water vapor diffuses through the ceilings into the cooler attic or roof cavity and may condense. Condensation leads to a reduction in insulation effects and, in extreme cases, to structural damage. Ventilation helps remove excess moisture before it can create a problem.

Effective roof ventilation requires both an air inlet and an outlet. Inlets normally consist of vents at the roof soffits. Typical outlet vents are ridge, gable, turbine, or power vents (see Figure 4). Ridge, gable, and turbine vents can function through natural convection air flow. Hot air will move to the outside from outlets placed near the roof's peak and be replaced by cooler air entering at the low-level soffit vents. For effective ventilation, the recommended total vent area (inlet plus outlet) is 1.5 square inches per square foot of ceiling area for the combination of continuous ridge vents and soffit vents, and 3 square inches per square foot of ceiling for gable or turbine vents plus soffit vents. Outlet vents should be sized to provide an outlet area equivalent to the

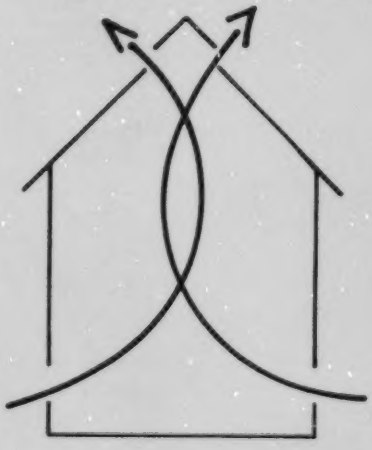


Figure 3. Stack effect ventilation removes hot air that accumulates near the ceiling.

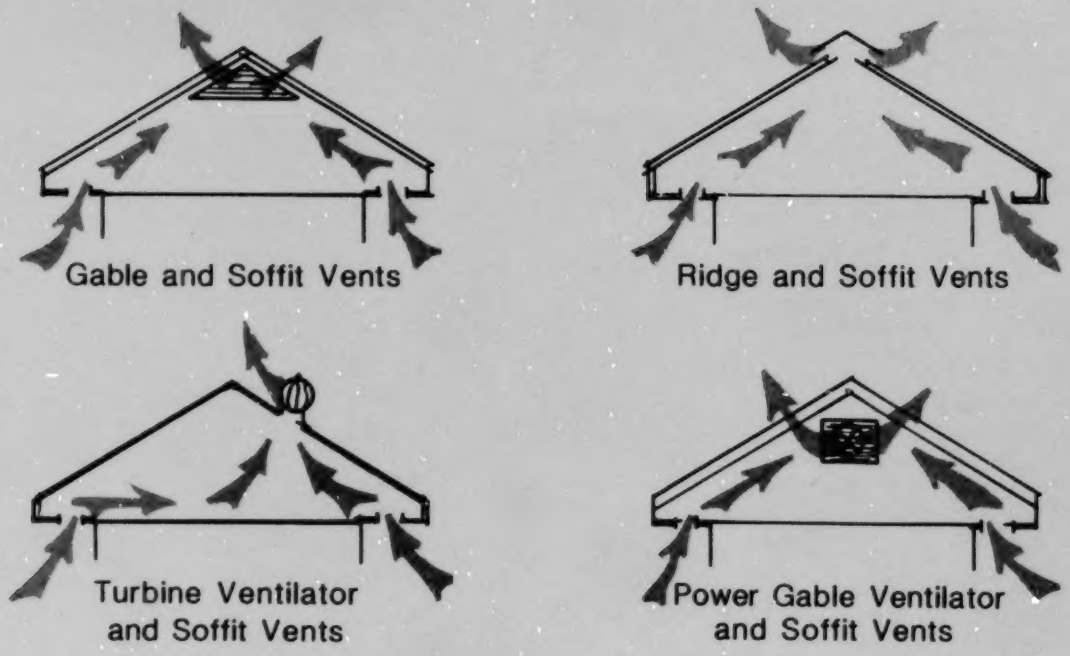


Figure 4. Typical roof venting techniques.

inlet area at the soffit. The combination of continuous soffit vents and ridge vents will move the greatest volume of air from the attic.

A power vent uses a thermostatically controlled ventilator, which is placed at the center of the attic near the roof's peak or in the gable end vent. The ventilator's fan capacity should be 0.7 CFM per square foot of ceiling area. For example, for a ceiling area of 1,500 square feet, a ventilator with 1,050 CFM capacity should be used. A very large house may require more than one ventilator. Soffit vents should be sized to provide 80 square inches of vent area for each 100 CFM of ventilator capacity.

Keep in mind that there must be a free flow path between the inlet and outlet vents. Air flow must not be obstructed by insulation, blocking, or structural members in the attic.

Vaulted or cathedral ceilings without an attic require particular attention in order to avoid excessive heat gains. An airspace between the roof decking and the insulation should be provided to allow for air flow from inlet to outlet. Care must be taken to ensure that insulation is installed properly and does not block the airspace. Larger rafters may be necessary to allow room for both the insulation and the airspace.

Good interior and roof ventilation can be very beneficial, and, in fact, many of these techniques were widely used in the southern part of the United States before the time of abundant and inexpensive energy. Now that energy costs are rising, it makes sense to ventilate a home and thus reduce the time when it is necessary to use air conditioning to maintain comfort.

REFERENCES

Chandra, S., Fairey, P. W. and Spain, R.S. *A Handbook for Designing Naturally Ventilated Buildings. Draft Report.* Cape Canaveral, FL: Florida Solar Energy Center, 1982.

Kusuda, T. and Bean, j.W. *Savings in Electric Cooling Energy by the Use of a Whole-House Fan.* National Bureau of Standards Technical Note 1138. Washington, DC: U.S. Government Printing Office, 1981.

2 Solar Energy

Arkansas Energy F

Solar Energy

INTRODUCTION

Solar energy has been a fruitful source of mythology from ancient times to the present. Ancient peoples visualized in the life-giving power of the sun radiant and sometimes terrifying gods and goddesses, from Krishna and Osiris to the Sun-Gods of the Incas and American Indians. Modern solar mythology tends to be more technical in nature, and often takes the form of an authoritative statement belittling the potential of the sun to contribute effective solutions to our current energy dilemma.

Civilizations considered "ar[illegible]ue," such as those of Greece and China in the millennia before the birth of Christ, adopted building and zoning principles in relationship to the sun that we consider farsighted and modern today. These civilizations, as well as the ancient peoples of the Americas, laid out homes and entire villages in obvious and conscious appreciation of the path the sun takes across the sky during the year. These layouts included building orientation that allowed for deep penetration and warming by the low winter sun, but blocked access by the high summer sun and achieved effective shading. Greek and Roman citizens drafted legal protection of their sun rights into zoning codes, since they appreciated the comfort afforded by a "heliocanthus," or solar room, in their homes. The Romans went so far as to build bathhouses heated by solar radiation for the pleasure of their bathers. In addition, these "primitive" civilizations were apparently quite at home in thermal masses, and villages of adobe, stucco, and rock stored up daytime heat for cold winter nights; or nighttime coolness for hot summer days.

The "greenhouse effect" is often invoked to explain why solar energy works so efficiently. The usual example is a locked car facing south on a cold sunny day. If you get back into the car after an hour or so, it will be quite hot inside, because sunlight (short-wave radiation) is converted to heat (long-wave radiation) after passing through the glass and being trapped; the glass that was transparent to the short-wave radiation is opaque to long-wave. In addition, dark-colored upholstery will absorb this heat. Yet, solar energy was heating homes effectively before the Romans put thin, translucent sheets of mica in the window openings to serve as "glass." Light and air were allowed to enter the windows and doors of heavy stone or stucco houses, and shutters closed over them at night. In the meantime, the walls of the houses, which absorbed sunlight all day long, radiated this energy back into the living spaces at night. This process was reversed during the summer. The shutters were kept closed all day and opened at night. Cool air was allowed to circulate, so that by morning the mass of the building was thoroughly cooled. This tended to temper the temperature of the living space during the hot day. Many early builders also provided balconies, awnings, and other architectural features that kept the direct blast of the sun off the building walls, thereby preventing unwanted absorption of heat.

It is difficult to believe that people have ignored for nearly twenty centries what the ancients took for granted, but here we are, rediscovering such unchanging principles as the difference in altitude between the summer sun and the winter sun, and the effect on sensible building design that this principle should have.

How people can take advantage of the great

quantities of solar energy available in Arkansas is explored in this booklet. There is enough sunlight falling every month in the state to supply more than the total annual energy demand of the entire United States. Arkansans are taking advantage of this energy source by means of everything from inexpensive home-made solar collectors and solar greenhouses to enormous, complicated electrical generating systems. Arkansas is the home of the first solar-powered college in the world, Mississippi County Community College at Blytheville; and the largest multi-family housing project in the world **cooled** with solar energy, in Conway.

SOLAR RADIATION

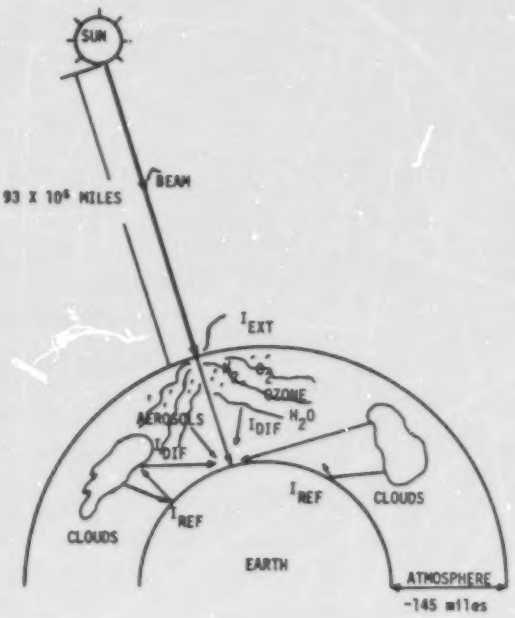
From the sun to the outer layer of the earth's atmosphere, the radiated energy is transmitted solely by direct beam because there is nothing in space to weaken it. The solar constant, or energy contained in the solar radiation by the time it reaches this point, is about 429 Btu/sq. ft./hr. (British thermal units per square foot per hour.) Upon entering the atmosphere, some of this radiant energy is absorbed by molecules of air, and some is scattered by dust, clouds, and aerosols.

The original direct beam radiation may be attenuated to between 250-325 Btu/sq. ft./hr. on a sunny day and to zero on a completely overcast day. Direct beam radiation accounts for a substantial portion of the solar energy converted by flat-plate collectors.

Diffuse radiation, which does not cast a shadow, can also be converted by flat-plate collectors and may amount to as much as 30-50 Btu/sq. ft./hr. Concentrating and focusing collectors cannot use diffuse radiation.

Reflected radiation refers to solar radiation reflected off ground surfaces and off the sky and, depending on the reflecting material, may provide a substantial boost to the radiation received by the collector. Stationary reflective surfaces should be avoided outside the south-facing windows of a house, since they may lead to overheating problems during the summer. On the other hand, aluminum and stainless steel reflectors, or an aluminum roof surface, can be used to augment the collecting ability of active collectors and photovoltaic panels. One Arkansas architect, James Lambeth, uses reflecting lenses in his designs to heat water and even to melt snow.

The University of Arkansas Engineering School at Fayetteville has done a comprehensive study of solar radiation in Arkansas for the Arkansas Energy Office. The study, which is the heart of the *Climate Atlas* published by the Energy Office, gives monthly figures on the solar radiation available in the different climatic areas of the state and conversion factors for surfaces tilted at different angles to make use of sunlight in collectors and buildings. It also provides a discussion of various other aspects of solar radiation.



This diagram from "A Solar Radiation Study for the State of Arkansas" by Turner and Battle shows how direct beam solar radiation is diffused by the earth's atmosphere. I_{EXT} *refers to the undiffused insolation radiating through the vacuum of outer space;* I_{DIF} *and* I_{REF} *refer to insolation diffused and reflected by ozone, water vapor, clouds, dust, aerosols, and molecules of air.*

INSULATE BEFORE YOU INSOLATE

The term "insolation" refers to the incidence of solar radiation upon a surface, whether a window, a solar collector, or a roof-top. Too many solar projects have failed simply because good sense was not used in constructing a building that would be energy-efficient and easy to heat or cool. **Insulation** is a cheap and reliable way to save energy; accordingly, proper insulating and other energy-efficient techniques should be given first priority in any new building or remodeling scheme, especially if solar features are being considered.

The minimum standards for new construction in a solar-heated or cooled building should be: Insulation totaling R-38 in ceilings, R-20 in walls, R-20 in floors; R-2 for windows, with R-6 for nighttime insulation, caulking, weatherstripping, and sealing to less than 0.5 air changes per hour. (Insulating efficiency of materials is measured by R numbers or values. "R" stands for resistance to winter heat loss or summer heat gain. The higher the R number, the more effective the material.)

Practicing energy-efficient building techniques will not only save money in heating and cooling the building, it will also limit the size of whatever auxiliary heating or cooling system is installed to back up the solar system, so that unnecessary expenditures for mechanical equipment can be avoided.

ACTIVE AND PASSIVE SOLAR APPLICATIONS

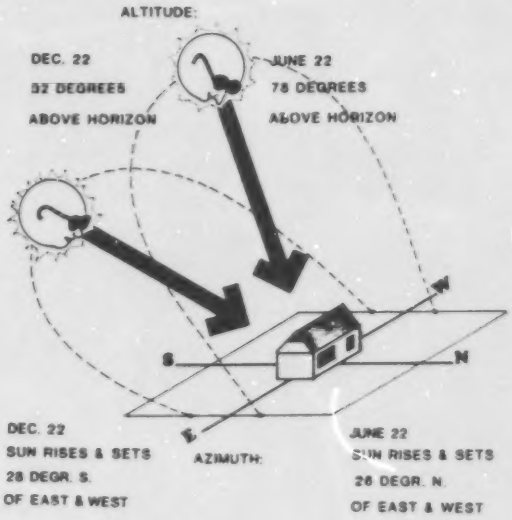
There are two categories of solar application: "active" and "passive." Passive solar applications, which this booklet will address first, rely on natural gravity or convection currents to transfer heat from a solar collection device to the living space. Examples of passive solar devices are solar greenhouses, mass walls and thermosyphon water heaters that do not require pumps. Active systems, on the other hand, generally require pumps, fans, and controllers to transfer heat from the solar collection devices to the place where it will be used.

PASSIVE DESIGN

SITING AND ORIENTATION

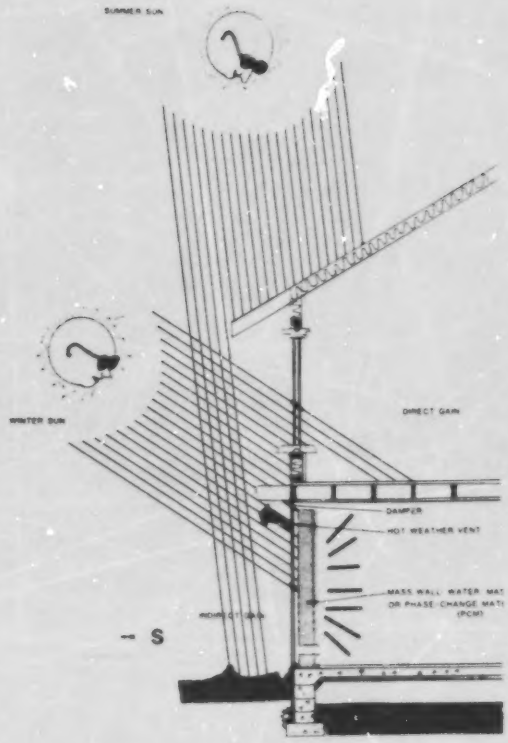
The first principle that a builder must consider in siting a building (or in remodeling an existing building) is the access the building site has to the sun. In most of Arkansas, true south is located 6° **east** of magnetic south, and a building that faces anywhere from **30°** east to **18°** west of magnetic south has a favorable solar orientation. However, you must also consider the shadows cast by trees, other buildings, and whatever obstructions to winter sunlight might exist at or near the site. You can do this either by carefully observing your site over the course of a winter day to make sure that it is not substantially shaded between 10:00 a.m. and 3:00 p.m. or, if your building is complex, and the site is, as well, a number of "sun-finders" are available that allow you to simulate the shadows cast by obstructions.

In Little Rock, the sun is at an angle of 32° from the horizontal at noon on December 22, and much lower in the sky for most of the day. It rises at 28° south of east and sets 28° south of west (azimuth). If there is a room in your house with a southern exposure, you will



The sun takes a different position in the sky as the seasons change. From Solar Greenhouses *by Albert Skiles.*

In this diagram, the sun shines directly into the living space upstairs, illustrating direct gain. Downstairs, a mass wall or "trombe" wall absorbs the sun's rays during the day and reradiates the stored heat into the living space at night, illustrating indirect gain. →



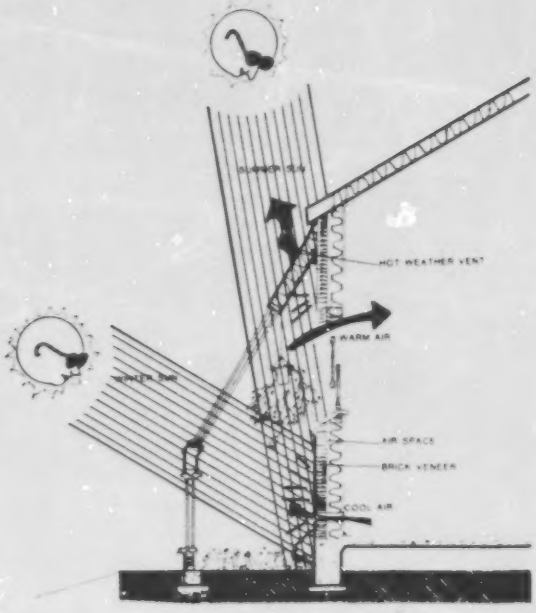
probably notice that, during the winter, the room is flooded with sunlight. At noon on June 22, the sun is beating down at an angle of 78° from the horizontal and rises and sets 26° north of due east and west. During the summer, there is rarely any direct sunlight in a room with a true southern exposure.

In planning the building, it is just as important to design for protection from the summer sun as for access to the winter sun. Overhangs and shading devices are important to keep direct sunlight out of the building during warm weather and care should be taken when putting windows on the east and west exposures of the building, since the sun will shine directly into these while it is low in the sky on summer mornings and late afternoons. In addition, the direction of prevailing breezes at the building site should be taken into account so that adequate natural ventilation can be incorporated into the building to cut the expenses of air-conditining in temperate weather.

PASSIVE HEATING

There are three terms generally used to describe the way a passive building works: Direct Gain, Indirect Gain, and Isolated Gain.

Direct gain refers to the heating of a space directly, as sunlight comes through a window or windows into that space; indirect gain is accomplished by placing some kind fo mass directly behind the window to absorb the solar gain during the day and release it at night; and isolated gain refers to the use of a solar room or greenhouse from which heat can be drawn into the living space. Most successful solar buildings include a wide variety and combination of techniques to fit the needs of the building occupants. A typical example is a house sited facing 45° east of due south. Southeast windows are used for direct gain, "waking up" the house early in the morning. Windows



This solar greenhouse is an example of isolated gain.

facing the southwest are backed by a masonry wall. Since this wall is heated after noon until evening, little heat is dissipated until it is really needed, and it is easier to store until the next morning. Since radiation is not collected and stored in great quantities early in the day, the house is not likely to overheat.

The solar greenhouse and trombe wall in the Little Rock home of Bob and Gerry Nash are shown here.

The Little Rock house in these photographs is a combination of all three passive approaches. The mass wall, constructed with concrete blocks poured full of concrete, is located about a foot behind the first-story glazing and painted black with high-temperature paint to absorb the solar energy striking it. It is eight inches thick and, since it takes about an hour for solar radiation to penetrate through one inch of masonry, at the end of eight hours of winter sunshine the wall is fully charged and begins to radiate heat into the living area. Next to the mass wall is a small greenhouse, which requires no extra heat from the house even on cold winter nights, and which contributes extra heat on sunny winter days. The upstairs of the house has typical direct gain features, including operable windows and sliding glass doors. No one of these features would have been sufficient to keep the house comfortable day and night, but the combination of the three does very well.

The south elevation of this Little Rock home of Bob and Gerry Nash, designed by Bob Bland, serves as a passive collector.

COMMERCIAL SOLAR BUILDINGS

Passive solar architecture need not be limited to single-family dwellings, as commercial buildings across the country prove. These include a 150-unit apartment building in Fort Smith, a new classroom-laboratory at South Arkansas

Sunlight comes through the south window-wall and heats the Ozark Mountain Smokehouse at Fayetteville.

University in East Camden, and the Ozark Mountain Smokehouse in Fayetteville. Buildings like schools and warehouses can be cheaply retrofitted with fiber-reinforced plastic translucent sheets, or glazing, to turn south-facing expanses of brick or concrete block into enormous heat-storing (mass) walls.

Nationally, the Farmers' Home Administration (FmHA) is considering guidelines mandating that all new single-family and multi-family developments built with FmHA money

be sun-tempered. In Arkansas, the most vigorous developer of buildings with some kind of solar component has been the Farmers' Home Administration, whose design portfolio includes homes of passive solar design.

In most large commercial buildings, the biggest damand for energy comes from lighting, followed closely by cooling. Architects have developed techniques to diffuse, reflect, and transmit natural light ("daylighting") throughout the building to reduce dependency on costly artificial lighting. Daylighting indirectly reduces cooling costs, since artificial lighting adds substantially to a commercial building's internal heat gain.

COST

Solar architecture should not cost any more than conventional buildings, since solar design merely rearranges the elements that already exist in a building's shell (glazing, insulation, masonry, shutters) in a careful and clever way so as to take advantage of the characteristics of the climate or the building site. There are no materials in a modern solar building that cannot be purchased at a lumberyard or hardware store; all that is required is extra planning and attention to detail during construction.

Insulation levels must be high; care must be taken that vapor barriers are correctly applied; all structural joints where air infiltration can occur, such as around window or door-frames and under the sills must be caulked with high-quality sealants; the millwork should be of good quality and insulating shades or shutters should be used.

There are as many ways to build solar buildings as there are designers, builders, and clients for them. A group of Arkansas lenders and appraisers heard a nationally-famous architect tell them that " . . . It makes about as much sense to leave solar out of the design of a new building as it does to leave reinforcement out of the foundation and insulation out of the walls."

HEAT LOSS AND GAIN

There are three types of heat movement: convection, conduction, and radiation.

Convection refers to the movement of heat in currents of air or water, and convective heat loss or heat gain, or infiltration, is usually the result of poorly weatherstripped doors and windows, uncaulked or unputtied window glass, door frames, window frames, and sills, poorly-fitting doors and windows, etc.

Conduction refers to movement of heat through a solid, much the way electricity moves through a wire. Some materials are good conductors of heat, hence poor insulators. Such materials include metal, stone, concrete, wood, plaster, and glass. Conductive heat loss and heat gain can be minimized by using plenty of insulation, and putting on storm windows or thermal pane windows. Insulating shades and shutters cut down conductive heat loss through windows even more effectively.

Radiative heat loss occurs when windows are left uncovered at night. Even triple-glazed windows are subject to radiative heat loss into the night sky. In addition, any type of storage mass, like an uninsulated masonry wall, will radiate stored heat out into the night sky. Typical means of preventing radiative heat loss (or gain) are insulating shutters or shades backed with a reflective sheet of mylar or aluminum.

DIRECT GAIN, INDIRECT GAIN, AND ISOLATED GAIN

Direct gain systems without any thermal storage may overheat during the day. At night, a backup source of heat must be used. In South Arkansas, no more than 16 to 18 square feet of south-facing glazing can be used for every 100 square feet of living area to be heated. However, in the Ozarks it is possible to build up to 25 square feet of glazing into the south wall for every 100 square feet of living area. If no thermal storage is used, overheating may be prevented on warm winter days by using either insulating shutters or simply opening some windows.

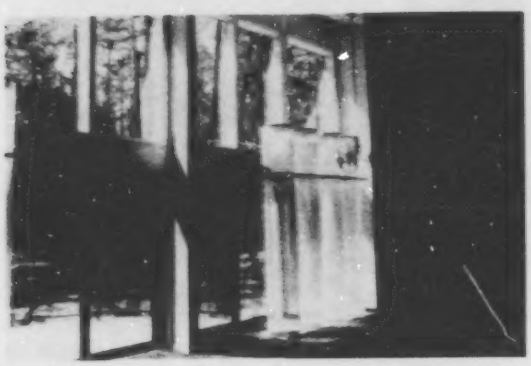
Indirect gain systems use thermal storage by definition. Rules of sizing the glazing and the thermal storage mass may be found in Anderson, Balcomb, et. al., *Passive Design Analysis*, Vol. II.

Isolated gain systems must be carefully designed to prevent overheating if the isolated space itself serves a function; e.g. solar greenhouse. However, if the system of isolated gain involves a room or a space in which no comfort level is required, this space may be allowed large temperature fluctuations. In any case, it is important to establish an efficient heat transfer mechanism between the sunspace or greenhouse and the living area that needs to be heated. For a more complete examination of isolated-gain systems, refer to the Arkansas Energy Office publication *Solar Greenhouses,* by Albert Skiles.

THERMAL STORAGE FOR PASSIVE SYSTEMS

Thermal storage can be incorporated into a building in a number of ways. In direct gain systems, the storage mass must be in the sunlight coming through the windows. Examples of thermal storage include mass walls, masonry floors and interior walls, beds of small rocks located under the building, tubes full of water, massive stone or brick chimneys, and fireplaces.

Thermal storage located out of the direct sun requires some means of enhancing the movement of solar heated air through it. One innovative designer has built an experimental house with thermal storage incorporated in special ceiling tiles upon which the solar gain is reflected using specular (highly reflective) venetian blinds and "light shelves," which bounce sunlight off the building's interior onto the ceiling.



The variety of thermal storage applications is limited only by the designer's imagination. Because of their ability to "freeze" into a solid at 60° to 81° F, phase-change materials are highly efficient at storing heat. As the living area cools off, the material solidifies and gives up the latent heat of fusion (the same principle that requires 144 extra Btu's per pound of water to be removed at 32° for water to become ice). Sodium sulfur decahydrate or calcium chloride hexahydrate, the most commonly used phase-change materials, are capable of storing 70 Btu's/lb./° F at 81°.

Water storage is less efficient and rock the least efficient of all. However, in architectural and structural terms, masonry and rock are the easiest to use. Phase-change salts are packaged in thermal storage rods made of anything from recycled coffee cans to sleek black polypropylene cylinders to ceiling tiles, and their big attraction is that a relatively small volume of material can be used.

Since phase-change materials can be designed to fuse at any temperature, they can be formulated to release their latent heat of fusion at 72° or 65° or whenever the designer deems the need for stored heat in the living space is the greatest. Water and rock are cheaper, however, and easier to incorporate into traditional designs.

So many variables must be taken into account when designing thermal storage that rules of thumb are hard to come by. The serious designer would do well to look carefully at the texts listed in the appendix to this booklet, particularly Volume II of *Passive Solar Design,* by Anderson, Balcomb, et al., for the calculations necessary to size storage to any particular situation.

The rule for thermal storage for direct gain cited by the authors of the *Los Alamos Passive Solar Design Handbook* states simply that for every square foot of solar glazing, the amount of masonry required in the storage mass is 3 × SSF pounds, where SSF represents the desired solar savings (in percent). Thus, if solar is

Tough fiberglass tubes filled with water store heat in this Hot Springs home designed by James Lambeth.
←

expected to save 10 percent of the otherwise anticipated energy needed to heat a building, there must be 30 pounds of masonry for every square foot of solar glazing. A thermal storage mass of 0.6 × SSF pounds of water per square foot of glazing is the recommended size of water storage.

The rule assumes that the mass is in the direct sun all day and is not insulated from the space to be heated. In addition, the mass must have an exposed surface area equal to at least three times the glazed area. If masonry is used, unless it is used as a trombe wall, it is not effective beyond a thickness of four to six inches — i.e., the heat stored in it to a depth greater than six inches will not be available to heat the living space. **If the mass is located completely out of the sun in back rooms, then about four times as much mass must be used.**

Thus, construction employing large amounts of concrete or masonry in walls and floor slabs, insulated on the outside rather than on the inside, represent effective use of thermal storage even if the masonry is not in the direct path of the sun's rays. The foundation wall of a house dug into the ground can double as a storage mass without any additional construction, but it must be within the convection path of solar-heated air to perform its function.

TABLE 1

Recommended Effective Thermal Storage Per Square Foot of Solar Collection Area

Expected Solar Savings	Pounds of Water	Pounds of Masonry
10%	6	60
20%	12	60
30%	18	90
40%	24	120
50%	30	150
60%	36	180
70%	42	210
80%	48	240
90%	54	270

From Anderson, Balcomb et al., Passive Design Analysis, Vol II, p. 26

The backup system should then be sized to make up whatever portion of the heating load is not met by the solar system. However, the backup must be sufficient to meet the entire heating load of the house if cloudy conditions prevail. One method to avoid installing an unnecessarily large backup system is to have two systems — one perhaps being a small, portable electric heater for unusual conditions. Another could be a small central gas or electric system, or perhaps a wood stove or central heating fireplace plus an inexpensive baseboard electric resistance heating system.

THERMAL MASS OPTIONS

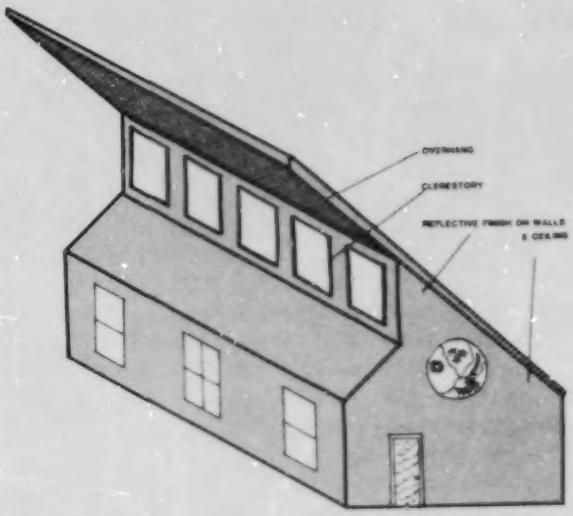
There is no unanimity of opinion among designers on the best thermal storage characteristics for a given building. Some, like William Shurcliffe, argue that thermal mass in large quantities can actually create thermal inefficiencies in cold climates, since four days of cold, sunless weather will turn this mass from a thermal tempering device into a giant heat sink, necessitating an overly-large and expensive auxiliary heating system. Shurcliffe argues further that it would be easy to heat a superinsulated house in bad weather with small, portable heaters, and that this would be less expensive than installing a large furnace to deal with heating a large thermal mass that has lost its solar charge.

Of course, this problem could be overcome by finding some means of insulating the thermal mass from the living space, but in the case of a dispersed mass, such as exists in concrete buildings, this could be impractical.

Steve Baer suggests that for hotter parts of the country, thermal storage is more appropriate than "superinsulation," since during the summer, a superinsulated house will eventually overheat after the doors are opened and closed a certain number of times, while thermal storage can be cooled at night and act as a tempering influence on the rest of the building during the day. However, this theory relies on cool nights being common. In Arkansas, large thermal storage could conceivably overheat and not cool down at night.

Some designers feel that the best way to use mass is to put it in the center of the house. Heat

and light are admitted through clerestory windows, and other glazing in the house is simply used conventionally — for the view and for admitting daylight to the periphery of the house. The clerestory does the main work of heating and daylighting the main living area of the house.



Clerestory windows are used to admit sunlight to thermal mass in the building.

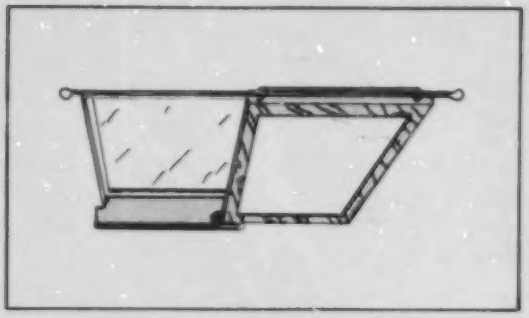
MOVABLE INSULATION

One of the most important considerations in a building designed with extra window area for solar gain is keeping heat from being lost back out through the glass at night or during cloudy weather. Not only is glass a poor insulator, it is also conducive to radiative heat loss at night. In terms of simple thermodynamics, the heat inside the house will radiate out through the glass into the night sky. In fact, the heat radiates to outer space and the earth's atmosphere does not stop it. In addition, unwanted heat will be gained through the glass in the summertime, even if the sun is not shining directly through it.

The best means of keeping south-facing windows from losing or gaining too much heat is to install some type of movable insulation that can be closed over the windows (and skylights) at night and during cold, cloudy, (or excessively hot) weather. Schemes for doing this range from popping pieces of rigid form insulation in and out at will to framing a hollow wall section that allows for a pocket shutter, that slides out of sight in the wall cavity when not in use and covers the window when desired.

The kind of window insulation used depends on the aesthetic needs of the inhabitants as well as the available space to swing, slide, or roll. But it is important that the insulating device have a fairly airtight fit over the window. Most insulating shutters are weatherstripped on the window frames just as if they were exterior doors.

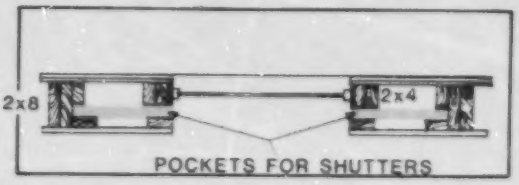
The problem of insulating the glazing in front of a mass wall seemed nearly insurmountable until just recently. Two solutions are now available. The first, for a trombe wall that has a gap at the top, is a narrow-profiled



SLIDING SHUTTER WITH OVERHEAD ROD

Two forms of window insulation are shown here. From Movable Insulation *by William Langdon.*

2x8 WALL FRAMING FOR POCKET SHUTTERS



shade roller that can be installed and pulled down at night by a series of strings and pulleys. It will drop between the wall and the glazing.

The other solution is not really an insulation, but an electroplated "selective" black surface on a thin copper foil, which is cemented to the mass wall. This surface is actually only a few molecules thick, absorbing as much as 95 percent of the solar radiation striking it and re-emitting almost none of it. Therefore, the mass wall will absorb radiation and will release most of it toward the living space, not back out through the glazing.

PASSIVE COOLING

The best examples of passive cooling in Arkansas are provided by the architecture of the era prior to air-conditioning. An excellent example of the architectural features that keep a building cool can be found in Little Rock's Union Train Station. The ceilings are high, and the rooms light-colored and designed for natural cross-ventilation. South Arkansas is full of houses built around a breezeway or "dogtrot," or surrounded by large porches with wide overhangs that shade the house all summer. The ceilings are high, sometimes as high as 14 feet, which tends to stratify hot air far above the living space and provides a natural engine for cross-ventilation. Most practical cooling methods being incorporated in today's buildings are a rediscovery of the old techniques, with some modern variations.

By means of a chart called a "nomograph," the size of a building overhang can be precisely calculated to let in the sunlight during a specified period of time before and after the winter solstice, and to shade the glass for any desired period of time before and after the summer solstice. A sample calculation for a house in the Little Rock area is illustrated in the appendix.

Another technique for modifying both summertime and wintertime temperatures is earth contact or earth sheltering. By digging a building into the ground, or piling (berming) earth up around it, the constant temperature of the earth and the associated heat sink can be used to make the building cooler in the summer and warmer during the winter.

Some Arkansas builders are experimenting with "cool tubes," or pipes buried at least four feet underground and running some distance, which bring in fresh air that has been cooled as a result of its journey underground.

Thermal chimneys also show promise in aiding hot-weather ventilation. The simplest thermal chimneys in use in our state can be seen on south Arkansas poultry houses. They are merely small box-like metal stacks set at regular intervals along the roof. The heat of the sun shining on the chimney creates an updraft and pulls hot air out of the building, at the same time pulling cool air in from the base of the building. Poultry farmers in North Arkansas suffered in a recent heatwave from the absence of thermal chimneys on their barns. For residential applications, the thermal chimney is constructed out of wood, with glazing on the south and west sides to enhance super-heating. Even simple metal duct pipes painted a dark blue or black will act as a thermal chimney. The updraft induced by this device can be coupled with "cool tubes" or some kind of earth contact of night-cooled storage mass.

A promising passive cooling technique being devised for hot, humid climates relies on "dessicant cooling." A dessicant is a substance through which fresh air may be drawn and dehumidified. When the air is moved around the living area at sufficient speed, a comfort effect based on moisture evaporating from the skin surface results, and temperatures in excess of currently-accepted "comfort levels" can be tolerated. The dessicant itself must be dried out periodically, and this can be accomplished with heat provided by solar collectors or some other heat source.

The use of roofponds also shows promise as a cooling technique. Roofponds are tough plastic liners full of water (like waterbeds), covered by an operable shutter. During hot weather, the shutter is kept closed during the day. At night it is opened, and the pond radiates heat out into the night sky, becoming substantially cooler than ambient temperature. The pond then becomes an effective heat sink during the day.

In cold weather, the process is reversed: the shutter is opened during the day and closed at night.

TAX CREDITS AND MORTGAGE SUBSIDIES FOR PASSIVE SOLAR

Both the federal government and the State of Arkansas recognize the benefits of saving energy by using passive techniques in buildings. Consequently, a number of financial incentives are available to stimulate the market in this area.

- The Arkansas Housing Development Agency, which issues bond money for mortgage loans to lenders and homebuyers, offers a rebate — $1,000 to the builder and $1,000 to the buyer — for a new solar home.

- Contrary to popular belief, the federal government **does** offer the 40 percent tax credit for passive systems, if they meet the following criteria:

  a. The system must have a collection area (glazing), an absorber, a storage mass, a heat distribution method, and a heat regulation device (thermal shutters, awnings, or the like).

  b. The materials and components of the system that serve a **significant structural function** or are **structural components** of a home, and labor costs of installing such components, are **not** eligible for the tax credit.

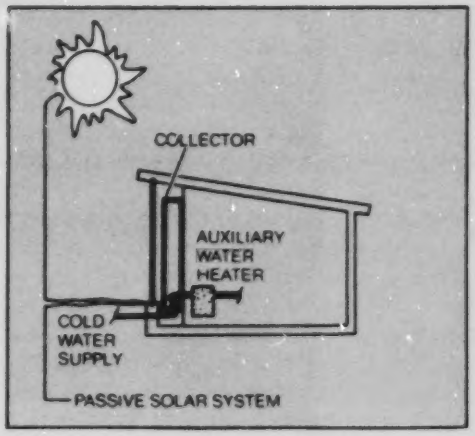
- The State of Arkansas offers a 100 percent tax deduction for any expenditure in a new or existing home that leads to using solar for heating or cooling or for heating water. In other words, if you build a new home that uses a mass wall and direct gain for heating, and put insulating shutters over your direct-gain windows, all the glazing, masonry, and insulating shutters qualify for the deduction for purposes of paying state income tax. This applies to sunspaces as well.

ACTIVE SYSTEMS

Active solar devices differ from passive designs in that they rely on separate systems of components: collectors, pumps, fans, storage elements, sensors, controllers, and differential thermostats. In passive systems the solar elements are an integral part of the building. Theoretically, active systems offer better and more precise building temperature control, although at somewhat greater expense and maintenance.

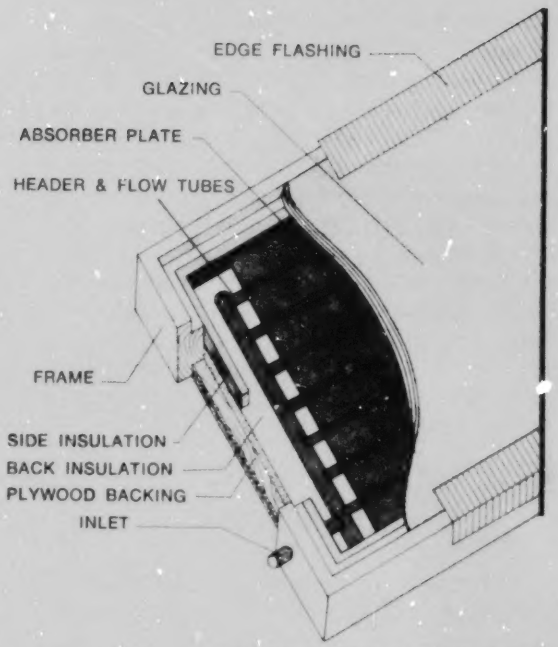
There are many "active" solar energy systems providing space heating, water heating, and space cooling in Arkansas. They range from homemade collectors costing $150 and providing heat for an American Legion Post in Calico Rock to a solar heating and air-conditioning system in a 50-unit apartment building that cost over $150,000.

All active systems **collect** energy, **store** it, and **distribute** it by various means. Collection is usually done in a **solar collector,** which consists of a cover plate or **glazing** that transmits solar radiation inside to an **absorber plate,** which ideally absorbs most of the solar energy and heats up. The absorber plate then transfers its heat to a **working fluid,** either a liquid of some type, perhaps water, or even air. In all but the simplest active solar-energy systems, this heat is then transferred by the working fluid into a **storage** medium; rock, water, or phase-change materials. A **thermostat** controls the delivery of heat from the heat storage to the living space. Other thermostats control the movement of the working fluid through the collector(s).



COLLECTORS

This diagram illustrates the common components of a typical **collector** and how they work. The efficiency of a solar energy collection and heat distribution system depends on the efficiency of the components and their interactions.



From *Solar Hot Water* by Nick Brown.

GLAZING

Glazings, or collector coverings, come in a wide variety of materials — from heavy, high quality glasses to lightweight plastics. Collectors may be single or double glazed. Most comercially-available collectors, designed to encounter a wide range of climates, are glazed with one or two layers of low-iron tempered glass. This kind of glass transmits over 90 percent of the incident solar radiation to the absorber plate and is nearly unbreakable (some dealers claim that an installer can literally walk

COMPARATIVE GLAZING CHART

		Cost Per Square Foot	Size	Trans-mit-tance	Weight Pounds Per Square Foot
GLASS	Tempered	$ 1.80	28, 34 or 46 x 76"	0.89	1.60
	Window	1.25	varies	0.90	1.60
FIBERGLASS	Filon	0.62	4' x 50'	0.86	0.25
	Sears	0.55	3' or 4' x 25'	0.86	0.25
	Kalwall	0.96	4' or 5' x 50'	0.88	0.29
PLASTIC	Lucite	1.14	4' x 8'	0.92	0.73
	Twinwall (two layers)	1.25	4' x 8'	0.89	0.50
	Acrylite (two layers)	2.15	6' x 8'	0.93	1.00
FILMS	Polyethelyne	0.03	8, 10, or 12 x 100'	0.80	0.03
	UV-Polyethylene	0.05	14, 16, or 18 x 100'	0.80	0.03
	Vinyl	0.60	28" or 36" x 50'	0.91	0.03
	Tedlar	0.60	64" x 100'	0.95	0.03
	Flexiguard	0.38	4' x 150'	0.89	0.05

From *Solar Greenhouses* by Albert Skiles.

on them). It is generally accepted that collectors in south Arkansas perform most efficiently with only one layer of glazing, since nighttime losses and losses due to windy, cold weather are not as serious as they are in north Arkansas, where double-glazed collectors are recommended. The advantage of a single-glazed collector is that it transmits more solar radiation to the absorber, weighs less, and costs less than a double-glazed collector. A glazing that is growing in popularity for both solar collector use and solar greenhouse use is a lightweight, double-skinned polycarbonate sheet, which performs as a double-glazing and is unbreakable and easy to install.

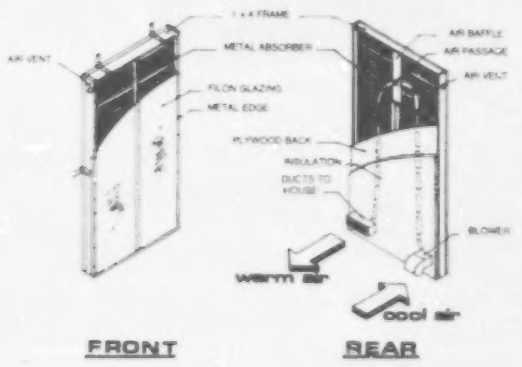
ABSORBERS

Absorbers are designed to absorb the sunlight transmitted through the glazing and turn it into heat, which is then transferred to the air or liquid (both known as "working fluids") being circulated through the collector. The absorber should transfer this heat as efficiently as possible, with a minimum being re-emitted out through the glazing (or through the back and sides of the collector).

In flat-plate collectors, the most efficient absorbers in use today are prefabricated plates of copper with integral fluid channels, or mechanically-bonded fluid channels. The more positive surface-area bonding between fluid channels and absorber plates, the more efficient heat transfer will be.

Absorber plates may be coated with a variety of treatments, ranging from flat black high-temperature paint (for homemade panels) to electroplated black chrome a few molecules thick, forming a "selective" coating (discussed previously).

It may not be economical in all cases to use the most efficient absorber available, since the cost of the absorber increases with increased efficiency. Several organizations, including the Office of Human Concern based in Rogers, have pioneered the development of very low cost but moderately efficient hot air collectors. Absorbers can be made of recycled materials: aluminum and tin roofing, printing plates, and screen wire. Even beer cans have been converted to solar collector absorber plates. Most hot-air collectors can be site-built rather than factory-built, and many new houses designed to be heated by air collectors have been built with the collectors assembled on site, integral with the roof. Complete solar-heating systems in Arkansas that rely on air-heating collectors have not been deemed particularly economical however, since the collectors do not perform any useful work during the summer, and the heating season here is short enough so that a well-designed passive building can meet well over 50 percent of the heating load.



Air circulates through a solar air heater. From Solar Heater by the Office of Human Concern, Rogers, Arkansas.

NON-METALLIC ABSORBERS

The development of a new class of non-metallic absorbers shows great promise in lowering collector costs and weight, as well as in increasing design flexibility. Also, since 99 percent of worldwide copper production is tied in some way to major oil company interests and is highly energy-intensive, these new developments may guarantee some independence for the solar industry from petroleum and mineral cartels.

The most available non-metallic absorber on the market, already widely used in commercial applications, is EDPM (ethylene-propylene-diene-monomer), a long name for synthetic rubber. The absorbers made of EPDM are mats extruded with a variable number of waterways or airways. These mats are impervious to

damage caused by freezing and are extremely effective in radiant heating applications as simple heat exchangers; for example, they may be cast in floor slabs to carry hot water from a boiler or from collectors. EPDM absorbers can be used in site-built or shop-built collectors, laid out over a roof with no glazing (for swimming pool heaters), or purchased in factory-built collectors.

EDPM has proven weatherability, having been in use for at least 20 years as insulation for high-tension electric wires. It is also a sealant for gaskets in a number of industries, including solar collectors. Typical commercial names of EPDM absorbers are SOLA-ROLL ™ and SUN-ROLL™.

Other non-metallic absorbers make use of the heat-transfer fluid itself as the absorber. The collector is made of clear tubes carrying a dark-colored fluid. Underneath the fluid passages, a light-reflective plate returns any radiation that passed through the fluid back into it.

CORROSION

The combination of dissimiliar metals such as copper and aluminum and any heat-transfer fluid that conducts electricity will lead to galvanic corrosion when the more chemically-active metals are connected. It can be avoided by:

1. Using a non-conductive heat transfer solution, such as a silicone or hydrocarbon oil.
2. Using one metal throughout the whole system. If the metal is copper and the transfer fluid is water, there is no need to add corrosion inhibitors.
3. Using corrosion inhibitors added to water/glycol antifreeze solutions. The corrosion inhibitors are attacked, rather than the metals in the system, and the solution must be maintained by regular checkinug of pH and regular replacement of the heat-transfer fluid.
4. Avoiding direct connections between dissimilar metals. The use of insulation washers or silicone hoses between dissimilar metals will reduce galvanic reactions at that point.

WORKING FLUIDS

Working fluids must pick the heat up off the absorber plate and transfer it to the heating load or the thermal storage. Liquids used as working fluids generally travel through tubes or channels; air travels over the absorber plate or through it, in the case of screen mesh. The ideal working fluid should have a relatively-high specific heat factor, or capacity to pick up heat from the absorber, combined with a relatively-low viscosity or density, to make pumping or blowing it easy.

The choice of a working fluid, or heat-transfer fluid, depends on a number of factors, including the degree of freeze-proofing needed and corrosion inhibition. Some collector manufacturers specify that their system warranties are only valid with a certain type of working fluid. The advantages and disadvantages of various types of working fluids are outlined below:

Water: Although water has the highest heat capacity of any working fluid and does not require a double-walled heat exchanger (often specified in plumbing codes for toxic or non-potable fluids), water will freeze; will accelerate corrosion, especially if chemically-active dissimilar metals like aluminum and copper are connected in the system through the flow of the fluid; and water (unless distilled) will deposit scale in the plumbing, leading to flow constrictions.

Glycol/Water Antifreeze Solution: Glycol solutions have lower freezing temperatures than water alone. At least 20 percent of the solution should be glycol. Food-grade **propylene glycol** is **non-toxic;** ethylene glycol is toxic and requires a double-walled heat exchanger. Do not use glycol solutions with galvanized pipe or with butyl rubber membranes common in certain types of expansion tanks. High temperatures and air mixing can cause glycol mixtures to acidify; solution pH should be checked periodically, and the solution should be replaced when necessary. Glycol solutions will leak through joints where water will not. Good seals and Teflon ™ tape should be used.

Paraffin Oils: Paraffin oils are nonconducting, so they inhibit galvanic corrosion; however, they are more viscous than water and may require larger pumps to move them around. They are also **toxic** and require a double-walled heat exchanger.

Silicones: Silicone heat transfer fluids are inert and non-toxic. They will not cause galvanic corrosion. However, they are more viscous than water and have lower specific heats, and a greater volume must be moved through the collector to transfer a given amount of heat. Therefore, they need larger pumps and a flow rate about 2½ times as great as that used for water. They are incompatible with expansion tanks fitted with neoprene or butyl rubber diaphragms. They also leak readily through piping flaws, such as improperly-soldered sweat joints, that will retain water.

Although there are several types of active systems using some type of liquid as a working fluid, the two most common types are **closed-loop** and **open-loop**. (See *Arkansas Energy Futures: Solar Hot Water*, by Nick Brown). Closed-loop systems separate the working fluid from the water being heated for household use by a heat-exchanger, and must be used when inedible or toxic working fluids are circulated through the collectors. Open-loop systems heat water directly before putting it into storage or into use, and are inexpensive. However, temperatures will damage open-loop systems unless precautions are taken to drain the water out of the collectors.

SIZING THE ACTIVE SYSTEM

Sizing the active system involves the same kinds of calculations needed to size the passive system: first, what is the heating load of the building, and how much of that load do you intend to supply with solar? From there, it is necessary to determine the efficiency of the collectors and heat exchangers, and the practical storage capacity. Climatic data, such as solar radiation incident on a horizontal or tilted surface anywhere in Arkansas, as well as average hours of sunshine per month, average daily high and low temperatures, and the like, can be found in the *Climate Atlas* published by the Arkansas Energy Office.

There are many ways to combine this information to size the active system. The most commonly used is the F-Chart, discussed at length in Beckman, Klein, and Duffie, *Solar Heating Design by the F-Chart Method*, Wiley, 1977. There are programs available for small and hand-held programmable calculators, like the TI-59, that eliminate time-consuming manual mathematical operations. A list of these programs can be found in *Analysis Methods for Solar Heating and Cooling Applications*, published by the Solar Energy Research

TABLE 3

TRANSFER FLUIDS

MEDIUM	SPECIFIC GRAVITY	VISCOSITY[1] CENTIPOISE	HEAT CAPACITY (BTU/lb. °F)	FREEZING POINT, °F.
Water	1.000	0.5 to 0.9	1.00	+32
50 wt. % Water-ethylene Glycol	1.05	1.2 to 4.4	.83	—33
50 wt. % Water-propylene Glycol	1.02	1.4 to 7.0	.85	—28
Paraffinic Oils	.82	12 to 30	.51	+15
Aromatic Oils	.85	0.6 to 0.8	.45	—100
Silicone Oils	.94	10 to 20	.38	—120

[1]Because viscosity is sensitive to temperature, values are given for a temperature range of approximately 80° F. to 140° F.

From *Installation Guidelines for DHW Systems*, P. 37.

RULES FOR DESIGN OF AN ACTIVE SYSTEM* FOR SPACE HEATING

ALL SYSTEMS	
Optimal Collector Tilt Angle For Space Heating:	Latitude + 15°
Orientation (in Arkansas)	18°E to 30°W of true south
LIQUID-BASED SYSTEMS	
Collector Flowrate:	.022 gal/min per sq. ft. of collectors
Heat Exchanger	90% efficient or better ($F_R'/F_R = 0.9$ or better)
Storage Capacity:	1.23 — 2 gal/sq. ft. of collectors
Load Heat Exchangers	Must be sized large enough to prevent high temperatures in storage. Baseboard heaters are not suitable for solar heating systems because they do not offer a large enough surface area for efficient heat exchange.
Pipe Insulation:	R-5 or better
AIR-BASED SYSTEMS:	
Collector Flowrate:	1-4 cfm/sq. ft. of collector
Storage Capacity:	0.5-1/5 cu. ft. rock/sq. ft. of collector
Rock Size: DUST FREE	0.5-1/5" dia. — uniformity is important
Bed Length in Direction of Air Flow:	4-8 ft.
Pressure Drops:	
Rock Bed:	0.1-0.3 in. H_2O
Collectors:	0.2-0.8 in. H_2O
Ductwork:	0.08 in. H_2O/100 ft.
Ductwork Insulation:	At least R-4. All seams must be sealed with duct tape.

*From Klein, Beckman, Duffie, **Designing Solar Systems Using The F-Chart Method.**

Institute.

These rules are approximate and are meant to illustrate relative properties of the active system. They should be taken as advisory, not as rigid rules.

THERMAL STORAGE FOR ACTIVE SYSTEMS

The same materials used for thermal storage in passive systems are used in active systems. In general, high temperatures in the solar store mean the system is operating inefficiently, either because the thermal storage is not coupled correctly to the heat load or because it is undersized. If the store exhibits temperatures too low to be of use in meeting the heat load, it may be oversized, or it may be losing energy through an uninsulated exposure.

The best operation of a solar energy system is obtained when the collected solar energy is used as soon as possible, to cut losses from storage. The control unit is best arranged so that when the thermostat in the house calls for heat, the system will deliver what it can from the storage unit, or directly from the collectors in the case of air systems. If the solar energy cannot meet the load, a second stage of the thermostat turns on the auxiliary furnace, or a couple of sticks of wood may be thrown into the stove.

The most common design error with rock storage beds is an attempt to move the solar-heated air through the entire bed. The pressure drop is enormous, and the bed never attains a useful temperature. Rock beds work best when **stratified**; i.e., the top of the bed is hot and the bottom is cool. The solar-heated air should be introduced at the **top** of the bed and forced down; return air from the house should be introduced at the **bottom** of the bed and pulled up. This will insure a maximum transfer of heat from the solar collectors to the warm layer of rock, and the return air from the house will be warmed and reintroduced as supply air.

SOLAR-ASSISTED HEAT PUMPS

It is possible to use flat-plate solar collectors in conjunction with a heat pump to increase the efficiency (coefficient of performance, or COP) of the heat pump. The heated air or water produced by the solar collectors can be used to augment the supply air or water that the heat pump uses to perform its heating function. A heat pump producing heat from 30-degree air may demonstrate a COP of 1.5.

The COP is defined as the relation between thermal energy produced and electrical energy used to produce it. When assisted with warm air from the collectors, the effective temperature

of the supply air may rise to 40 degrees, with a corresponding rise in COP.

The University of Arkansas at Fayetteville is currently researching the interactive performance of solar hot-air collectors and an air-to-air heat pump at the Engineering Experiment Station under a grant from the Arkansas Energy Office.

The Otter Creek Elementary School in southwest Little Rock was designed for the eventual addition of solar collectors to augment the operation of the heat pumps currently heating the building. Benham-Blair Affiliates, Inc., of Little Rock, which designed and engineered the school, has several similar projects on the drawing boards. This particular heat pump system is water-to-air, which is compatible with a hydronic solar collection system.

CONCENTRATING AND FOCUSING COLLECTORS

Concentrating and focusing collectors are available to provide far higher temperatures than flat-plate and evacuated-tube collectors. The town of Crosbyton, Texas, provides most of its electricity from a field of parabolic dish collectors, which provide 600-degree steam to run a conventional turbine-generator.

The most popular focusing collectors generally require tracking devices to follow the altitude and azimuth of the sun, since they work well only with direct beam insolation, and are very selective of the angle of incidence needed for full efficiency. Focusing collectors cannot make use of diffuse radiation the way flat-plate collectors can.

The only example of a commercial application of focusing collectors in Arkansas is at Mississippi County Community College at Blytheville, where a field of parabolic trough-type collectors tracks the sun to provide electricity and hot water for the school.

Concentration can also be achieved by the use of special lenses, such as fresnel lenses, which act as magnifiers to concentrate the intensity of sunlight from five to fifty times. Fresnel lenses are commonly used in photovoltaic arrays, since it is more economical to intensify and concentrate the sunlight in an array of given size, thus raising the potential output of the array, than to increase the size of the array.

SOLAR INDUSTRIAL PROCESS HEAT

Many types of industrial processes, such as wood-drying, textile washing and dyeing, sterilizing soup cans, and production of electricity are suitable for solar energy applications.

Some examples of solar installations in industry are: a lumber kiln in Mississippi, a soup-canning factory in California, cement-block drying in Pennsylvania, and textile-dyeing in Alabama.

The federal Department of Energy is currently seeking Arkansas industries interested in participating in a cost-sharing project to develop modular solar systems for industry, either to retrofit existing plants or build into new plants. If interested, contact:

George Papas
DOE Albuquerque Operations Office
P.O. Box 5400
Albuquerque, New Mexico 87115

An even more ambitious type of solar thermal project is illustrated by the solar furnace located in the cold but sunny French Pyrenees mountains. The facility consists of heliostats (sun-tracking mirrors) that focus an intensely-concentrated beam of sunlight onto the top of a tower. The tower is actually a laboratory, and high-temperature materials research is carried out behind quartz windows at the focal point of the heliostats. The French government saves hundreds of thousands of dollars in fuel costs by using this facility rather than high-temperature electric furnaces. In a project of this sort, sunlight has the demonstrated ability to burn holes in heavy armor plating in a matter of seconds.

The same principles are put to use in several American experimental facilities designed to "repower" conventional thermal electric generating plants and give them a new energy source. Such approaches also aid oil companies in secondary and tertiary recovery of crude oil from tight formations. The oil companies normally burn up to 25 percent of the recovered oil to produce the steam needed to

loosen up and liquefy the heavy crude in the formation, and high-temperature steam produced by fields of heliostats may be economical as oil becomes more precious. In Barstow, California, a field of heliostats focusing on a "power tower" will soon be producing 10 megawatts of solar electricity.

AGRICULTURAL USES OF SOLAR ENERGY

Solar energy applications in agriculture include lumber drying, crop drying, irrigation, livestock shelters, and dairy hot water. Several examples of agricultural solar energy uses can be found in Arkansas.

Dr. Tom Rokeby at the University of Arkansas in Fayetteville has been working for several years with poultry shelters heated by air collectors. James Lambeth, a Fayetteville architect, has designed a passively-heated poultry shelter. The basic premise being investigated in modern poultry shelter construction is the savings of propane possible by isolating the brooder section in a well-insulated portion of the building and heating it with solar energy.

Small solar lumber kilns can be found in Eureka Springs, Fox, and Ozone. These kilns operate on passive principles, circulating warm air around the batch of lumber stock to be dried. They were built primarily to dry hardwoods for furniture rather than large batches of softwood for building purposes.

Irrigation pumps can be powered by solar energy. Photovoltaic arrays can be used to run electric pumps, or shaft power can be derived directly from a concentrating collector hooked up to a Rankine or Stirling-type engine.

Solar crop-drying or grain-drying installations in Arkansas are few, but the potential for their application is certainly great. Solar energy can replace expensive propane either by designing grain-drying bins to take advantage of passive solar principles or by retrofitting existing bins with solar air collectors and circulating that air much as propane-heated air is circulated now.

The Arkansas Energy Office intends to promote further research in this field, and hopes to encourage the publication of comprehensive data and designs in the near future.

SOLAR AIR-CONDITIONING

The principle of air-conditioning that makes it susceptible to being solar-powered is as old-fashioned as the gas refrigerator. A low-temperature refrigerant, usually lithium bromide (LiBr), is vaporized at temperatures ranging from 170° to 200° F by hot water from either a boiler or a bank of solar collectors. The latent heat of vaporization is provided by a heat exchange that chills water for circulation through a building or through coils in an air handler, removing excess heat from the building and dumping it in a cooling tower. The hotter the sun shines on the collectors, the more efficiently the chiller works. Although most solar air-conditioning equipment on the market today is relatively inefficient, requiring some kind of concentrating collectors to run chillers rated at 210° F, some of the new equipment is efficient enough to use water at only 170°, which can be produced by flat-plate collectors. The Farmers' Home Administration (FmHA) has invested in a solar heating and cooling system in a new 50-unit apartment building in Conway. Although the system added about $185,000 to the initial cost of the project, Farmers' Home calculations show that, within the 25-year lifespan of the system, the energy savings will pay not only for the system itself but for the entire cost of constructing the project, including the cost of the land, water, and sewer hookups, and interest. This amounts to a major savings of tax dollars, and FmHA is planning similar projects in Batesville, Morrilton, and Gravel Ridge.

COMMERCIAL SYSTEMS

Heating domestic and service hot water using commercially-available solar energy systems appears to be the most cost-effective and widespread application of commercial solar energy systems, although the heating and cooling systems mentioned above pose interesting challenges. Solar domestic water heating in multi-family projects or clusters of dwelling units can service a number of families from a common bank of collectors, controls, and storage, cutting the per-family cost of the equipment dramatically from the cost of single-family applications.

Large users of hot water, such as hospitals, laundries, and restaurants, should investigate the use of solar to heat some portion of the water they use. The imminent federal deregulation of natural gas prices will triple energy costs, and solar power may soon be the only source of energy whose price is stable enough for accurate economic predictions. The technology of commercial water heating systems is straightforward, and there are enough experienced engineers and installers to guarantee the successful operation of such systems.

Two Arkansas banks have installed heating and cooling systems that rely on evacuated tube-type solar collectors. The First National Bank of Paragould and the White Hall Branch of the First Federal Savings and Loan Association of Pine Bluff are demonstrating to their customers that financial institutions may take the lead in establishing the new conservation-related technologies. The collectors consist of two concentric tubes from which all the air has effectively been evacuated. The absorber is located in the center of the tube and runs along its entire length (four to eight feet). These collectors are extremely efficient, because they emit virtually none of the absorbed sunlight back into the atmosphere. The vacuum around the absorber makes an excellent insulator. Higher temperatures are possible with evacuated tube collectors than with ordinary flat-plate collectors. These higher temperatures allow the chiller to work more efficiently. Evacuated tube collectors, however, are fragile, and expensive to repair. When using them, the working fluid should not be introduced into a system has been sitting out in the sun. The collectors will have become extremely hot, since there will have been no heat transfer going on, and introducing a working fluid at room temperature will cause them to break, much as a hot baking dish will break if cold water is poured into it.

COLLECTOR STANDARDS AND TESTING

In order to determine the quality of a solar collector, as well as engineer a system intelligently, it is important to be able to predict the performance of the collector under a wide variety of climatic conditions. There are a number of independent testing labratories across the country that simulate solar radiation and weather conditions and monitor the performance of collectors on test stands. These testing facilities include the Florida Solar Energy Center, Wyle Labs in Huntsville, Alabama, and Desert Sunshine Exposure Tests near Phoenix, Arizona.

Efficiency of the collector is measured as a function of how much of the incident solar radiation is converted to heat in the working fluid and how much is lost through re-radiation and conduction through the sides and back of the collector. The efficiency is measured at many different temperatures representing a wide range of actual weather conditions expressed as a delta t, or difference between fluid temperature coming into the collector and ambient temperature. Collector efficiency typically falls from 75 to 80 percent at a delta t of zero to around 30 to 40 percent at a high delta t representing a cold winter day.

Collectors are also tested for durability under "stagnation." Stagnation is the condition of sitting out in the sun without any working fluid running through the collector taking heat away. Collectors with selective absorbers may reach 300 to 400° F under stagnant conditions, causing insulation to outgas or catch fire, cover plates to deteriorate or warp, or solder joints and sealants to break down. Therefore, these tests are important to determine how durable collectors are under unusual but not necessarily unlikely conditions of stress. Such testing has led to significant improvement in collector construction methods and materials.

Several states have certification requirements for solar collectors sold commercially. Often, these requirements may overlap, but many states refuse to accept a certification that they do not specify. In an effort to overcome the expense and effort of fulfilling several different but duplicative certification requirements, the solar industry and the energy offices of all the states have agreed to set up an organization to draft a uniform set of standards for solar equipment and installation acceptable to all. The organization, called the Solar Rating and Certification Corporation, has been established and has already circulated first and second drafts of several proposed standards for solar water heating equipment.

At the present time, Arkansas does not require any certification of solar equipment sold within the state. *The Solar Products Specification Guide*, distributed by the publisher of **Solar Age** magazine, is available at the Arkansas Energy Office for people who wish to investigate the test results of commercially-available solar equipment. The *Guide* lists equipment of all types, from swimming-pool heaters to industrial concentrators, with detailed specifications on performance, size, weight, proper usage, and sometimes even cost.

PHOTOVOLTAICS

The work that can be done by sunlight is not limited to production of heat. Plants, for instance, synthesize food in the presence of sunlight. Photovoltaic cells use delicate chemical/electrical reactions to produce electricity in the presence of sunlight.

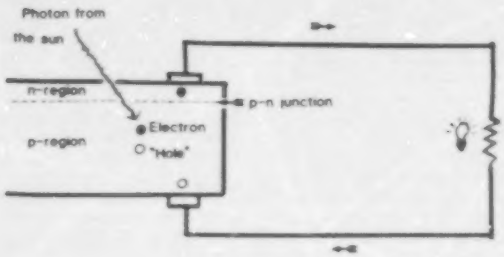
SEMICONDUCTORS

Photovoltaic (PV) cells are made out of semiconductor material — material that usually does not conduct electricity but can do so if a sufficient amount of light or heat is present. Most photovoltaic cells are made of high-purity crystalline silicon (Si), although higher-efficiency and more expensive cells are being made with gallium arsenide (GaAs), cadmium sulphide (CdS), and cuprous sulphide (Cu_2S).

Semiconductor materials produce electricity from sunlight at an atomic level. The energy absorbed from incoming photons dislocates electrons from their position in the crystal lattice, creating a "charge pair" — a free electron (negatively charged) and a positively-charged "hole" where the electron wants to be and from where it departed. If the cell consisted only of silicon, however, this charge pair would revert to its previous configuration within a millionth of a second, and no measureable or usable electricity would be produced.

DOPANTS

The electrical activity of the semiconductor can be dramatically improved by the addition of very small amounts of impurity elements, called "dopants." In order for the dopants to work properly, the original semiconductor material must be extremely pure. The addition of a tiny amount of phosphorous to the molten silicon creates an "n-type" region with an excess of free electrons. Doping the silicon with boron atoms creates a p-type region, with an excess of free electrons. Most solar cells are constructed by placing a layer of n-type silicon on top of a layer of p-type silicon, creating a p-n junction. When sunlight strikes the surface of the solar cell and creates charge pairs near the p-n junction, the electric field near the junction causes the charges to separate, electrons moving to the n-type side and holes to the p-type side. If the p-side and n-side are connected by an external circuit, electricity will flow as long as the sun shines on the cell.



Operation of a solar cell is shown in a diagram from **SUNWORLD** *magazine.*

CELL FABRICATION

There are many ways to fabricate solar cells, and research seems to come up with a new way every two weeks. The most established and costly method involves melting a batch of ultrapure silicon in a crucible and adding just enough boron to create a p-type silicon. A perfect crystal is then grown from the melt and carefully drawn out into the three or four-inch diameter cylinder, four feet long. It is then sawed into wafers — the individual cells — by an incredibly wasteful process. About 50 percent of the silicon ends up as sawdust. Then one face of each wafer is exposed to phosphorous at high temperatures, creating a thin n-type layer. Electric contacts are then attached to the front and back of the wafer, and the cell

is sealed in a transparent protective coating.

Several new methods of photovoltaic cell fabrication promise to bring costs down. Among these many methods are: amorphous rather than crystalline silicon production, deposited on a substrate; vapor-deposition rather than molten silicon crystallization; continuous ribbon production; square rather than round bars of silicon (allowing for more compact panels); and cutting the silicon using lasers rather than mechanical saws. Every manufacturer of cells has a different method of fabrication, and competition in the field is keen. Typically, cell efficiencies are around 10 to 12 percent, although cells with a 23 percent conversion efficiency have been manufactured in laboratory experiments.

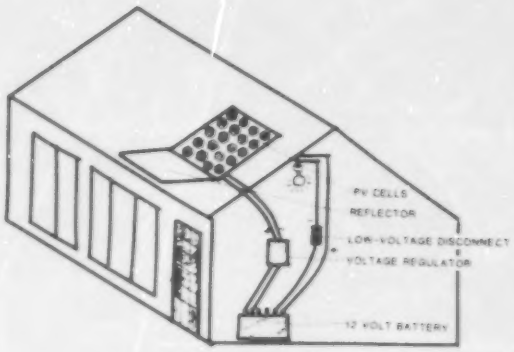
SMALL-SCALE RESIDENTIAL PHOTOVOLTAICS

There are over two dozen Arkansas homes currently using photovoltaics to meet their electric demand. Most of these homes are too far from utility lines to afford a utility hook-up. In every case, the builders have minimized their energy demands by building tight, passive solar homes, and by using small, efficient appliances. Rather than spend a great deal of money to put in large photovoltaic energy systems, they have successfully reduced the energy demands of their homes so that, for a minimal expenditure on photovoltaic cells and batteries, they can be free of electricity costs for the life of the home.

Small photovoltaic arrays are compatible with relatively-unsophisticated systems of energy storage. Telephone companies, aluminum refiners, and other firms use heavy-duty batteries that are discarded long before their useful life has ended. Even large truck batteries can be found that have enough life left in them to be useful. A deep-cycle battery can be 70 percent discharged in the first day of use; a shallow-cycle battery can only be 25 percent discharged in the first day and is therefore better suited to use with photovoltaics and possible stretches of sunless days.

Twelve-volt direct current appliances can be purchased through marine and recreational supply houses. By using solar, wood, and/or propane to heat the living space and domestic hot water, electric use is limited to the most efficient end-uses: fluorescent lighting, refrigerator, TV/stereo, pumps, power tools.

Photovoltaic power can be converted to AC (alternating current) by use of a device called a "synchronous inverter" that cycles the power backward and forward. Larger photovoltaic systems that power conventional appliances use a synchronous inverter in their circuits. It is, of course, also necessary to use a synchronous inverter when electricity is cogenerated for sale to the utility.



The sun furnishes lighting for this home in this photovoltaic system.

SELLING ELECTRICITY TO THE POWER COMPANY

Federal regulations enacted under the Public Utility Regulatory and Policy Act of 1978 (PURPA) enjoin electric utilities to buy power from small power producers, such as a homeowner or a business that uses photovoltaic cells or windmills or hydroelectric power, at a reasonable rate. This "buy-back rate" for home-produced power often amounts to close to what the homeowner pays for power.

MISSISSIPPI COUNTY COMMUNITY COLLEGE AND LARGE-SCALE PHOTOVOLTAICS

At Mississippi County Community College in Blytheville, a very large photovoltaic facility has been built to power the college. Under an agreement with Arkansas-Missouri Power Company, the college can sell excess electricity to the power company for the same price at which it buys electricity when the photovoltaics are not producing enough power. Thus, the electric utility becomes the storage battery in this system.

In a large system like the one in Blytheville, the typical efficiencies of 12 percent or so become very costly. Since photovoltaic cells operate best when reasonably cool, but concentrating systems used in most large-scale applications produce a great deal of heat, it is possible to use the thermal energy produced as well, which raises the total system efficiency to a much more acceptable 50 to 60 percent. Conventional electrical generating facilities deliver electricity to the user at about 28 percent efficiency. The fluid used to keep the photovoltaic cells cool is passed through a heat-exchanger and is used as in any active system.

INTERNATIONAL MARKETS

The world-wide market for photovoltaics is already large and is getting bigger all the time. In many underdeveloped countries, it would be far more expensive and less practical to rely on the eventual creation of a centralized grid network to provide electricity than to create a decentralized network emphasizing small-scale power production used locally. So much of the underdeveloped world is remote from existing power grids that photovoltaics make irrefutable economic sense for any number of applications.

A good case in point is an Egyptian village that bought a photovoltaic array to replace a diesel engine that was powering its irrigation pumps. In spite of the initial cost of the photovoltaic array, the savings in operating costs were so great that the village could afford to irrigate two crops a year rather than one, and agricultural output literally doubled.

In the sixties, when the National Aeronautics and Space Administration was using photovoltaics to power the electronics in its spacecaft, the cost for the arrays ran about $75 to $100 per watt. Today, in spite of inflation, costs are down $5 to $10 per watt. There is a lot of investment going on, and observers think that by 1990 photovoltaics will be directly cost-competitive with coal-fired electricity. The biggest investors in photovoltaic companies are the major oil companies, who view electricity from the sun as possibly the next big energy strike.

SOLAR PONDS

Any pond converts insolation to heat, but most lose that heat quickly through vertical transfer of heat within the body of the pond and through evaporation and heat transfer at its surface. Solar ponds artifically prevent both vertical convection and surface evaporation and convection. Therefore, solar ponds can be used to convert solar energy into thermal energy for such uses as space heating and water heating. In addition, the solar pond is probably the simplest technique that can be used for direct thermal conversion of solar energy.

A solar pond is a collector of solar radiation, while at the same time, it is a large body of thermal storage. It offers the advantage of massive essential thermal storage, eliminating the problems of non-continuous solar radiation.

Advantages of the solar pond as a source of energy are many. They are low-cost, even less expensive per unit collector and per thermal output than flat-plate collectors. The costs range from $10 to $40 per square meter. At high-temperature operations, solar ponds are more efficient than flat-plate collectors. They require no back-up systems for space heating, water heating and low-temperature industrial process heating.

This is a significant advantage over most other renewable energy technologies. A typical solar pond contains 20 weeks of thermal storage, and they are simple to build and easy to maintain. Most importantly, solar ponds have the potential to displace from one to six quads of fossil fuels in the near and immediate future

for rural and suburban areas.

The size of a solar pond depends on its location, because allowances must be made for the different climates. It has been determined with consideration of these allowances that one-half to two acres of pond would be sufficient to serve roughly 25 to 50 households. Of course, a deeper pond provides more thermal capacity and allows higher minimum storage temperatures to be maintained for the same surface area.

Solar pond applications can provide low-temperature residential or commercial space heating and water heating, as well as low-temperature industrial or agricultural process heat. The thermal energy from these ponds can also provide preheating for high-temperature industrial process heat applications. Combined with thermoelectric devices, solar ponds may be used for electric power generation. Another application for solar ponds is that they may be used for cooling, by using the heat to run an absorption chiller.

Solar ponds are designed to develop a very large quantity of stored low-temperature heat that is almost immune to the daily fluctuations in climate, and which maintains its temperature through cold winters.

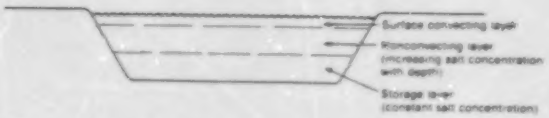
Different types of solar ponds include the salt gradient ponds, the deep saltless ponds, and the shallow solar ponds.

SALT GRADIENT PONDS

Salt gradient ponds are the most highly developed type of solar pond. The salt gradient contains a layered (stratified) salt solution. The surface water contains little or no salt. Increasing with depth, the salt reaches a high concentration near the bottom causing thermal buoyancy convection to be suppressed.

Thermal buoyancy, or warm water rising, is normally the chief mode of heat transfer in a body of water exposed to sunlight. With this convection suppressed, the salt gradient pond retains much of the heat absorbed from incident radiation. Whatever solar radiation is not absorbed in the water on the way down is absorbed on the bottom.

The salt gradient pond has three layers: the surface convecting layer, the non-convecting layer, and the storage layer. The salts most commonly used for this type of pond are NaCl and $MgCl_2$.



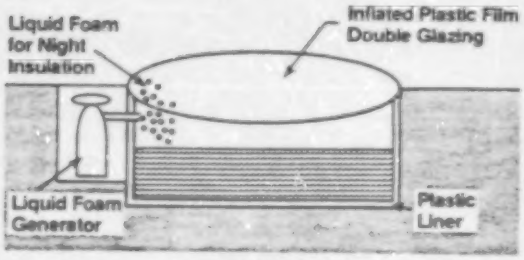
Elements of a salt gradient solar pond are shown here.

DEEP SALTLESS PONDS

Deep saltless ponds suppress thermal buoyancy convection by retarding heat losses from the surface of the pond. This is achieved by glazing the surface of the pond and using additional night insulation. Deep saltless ponds require pipes and plumbing to shuttle the water out of the water bags that line the pond into storage tanks that hold the water at night. Insulation is required under the water bags because the ground cools off each night after the water is removed from the bags.

Another form of insulation for the pond would be liquid foam between the double glazing and the water level. The foam, much like that used by firefighters, eliminates the pipes, pumps and plumbing used to transfer the water at night. By leaving the water in the pond at night, the cost of a deep saltless pond is reduced.

At this time, deep saltless ponds are still in the early stages of development.

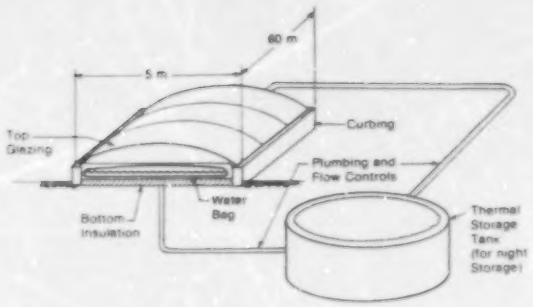


Design for a deep saltless pond is shown here.

SHALLOW SOLAR PONDS

Shallow solar ponds work much like flat-plate collectors. Water approximately 10 centimeters in depth is enclosed in large, shallow plastic bags with a blackened, insulated bottom. The top of the pond is covered by glazing. Incident insolation heats the shallow solar pond. Water is pumped from the bags to an underground tank for nighttime storage and back into the water bags each morning.

A major advantage of shallow solar ponds is that they may be located on rooftops of structures that can adequately support the weight. This keeps the solar pond from being limited to urban and suburban areas. However, the shallow solar pond is a disadvantage in that it requires much plumbing and pumping equipment, plus a separate nighttime thermal storage, making it more expensive to operate than the deep solar pond.

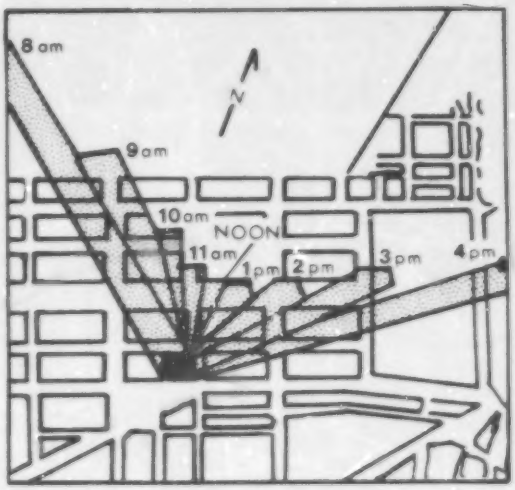


Elements of a shallow solar pond include flow controls.

SOLAR ACCESS

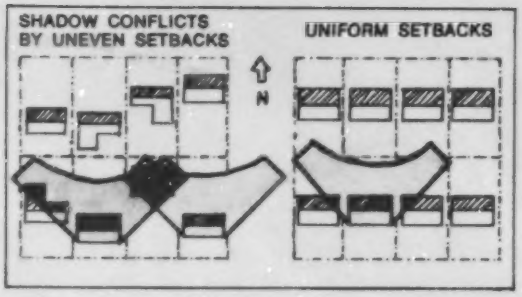
Many states and localities have decided that if all new costruction is oriented to solar designs, or the possibility is preserved to build solar buildings, the community as a whole will benefit, thanks to lower overall energy costs. In such cases, the communities have passed zoning ordiances that preserve the access to sunlight of residential and commercial structures. Thus, we come full circle to the codes of ancient Greece and Rome, which also protected solar access for their citizens and encouraged town planners to lay out their villages to take maximum advantage of the sun.

Boston, Massachusetts, enacted the first solar access legislation in the United States. Sunlight was correctly believed to be beneficial in its effect upon health, happiness, and warmth, and the city fathers were concerned that skyscraper costruction would leave vast areas of the city in deep shadow. An architect named William Atkinson was commissioned to study the effect of tall buildings on patterns of shading in adjacent neighborhoods, and as a result of his studies, the Boston City Council passed an ordinance in 1904 limiting the height of buildings.



Shadows cast in December by a 300-foot building at Boston are shown here. From A Golden Thread *by Butti and Perlin.*

There are several instances in which people have built a solar home only to have a neighbor shade the home because no easement was obtained for sun rights. If the state or municipality in which you live has not passed specific legislation regarding solar access (and to date no municipality in Arkansas has), your only recourse is to obtain an easement for sun rights from potential neighbors. For instance, when developing a lot in a subdivision, approach the owner of the subdivision and ask that lots adjacent to yours be restricted in the shape or height of the buildings that can be built there.



Conflicts in solar access caused by uneven setbacks are show here. From Protecting Solar Access for Residential Development *by the Federal Housing and Urban Development Department.*

SOLAR ECONOMICS AND FINANCING

Any analysis of the economics of solar must be based on the fact that the use of solar hardware or solar design tends to stabilize energy costs over the lifetime of the solar system or the solar dwelling. In other words, **hardware** costs, which are **fixed**, replace **energy** costs, which are not.

ADD-ON SYSTEMS

The goal in any attempt to finance an add-on solar system is to make the monthly mortgage or service payments for the equipment less than the monthly savings in energy costs. In other words, if a homeowner wants to add a $2,000 solar water heating system to a home, it should be financed in such a way that it costs less per month than the electricity or gas to be saved by changing over to solar — or about $12.

How can this be done? There are several methods of "painless" solar financing for add-on systems. Probably the most attractive is offered by a San Diego bank for its mortgagees. If a homeowner whose mortgage the bank holds decides to buy a solar water-heating system, the bank simply extends the mortgage a few months past the 30-year period to pay for the solar equipment.

This amounts to a 30-year loan for a system costing only about $2,000! The homeowner doesn't actually pay a penny on the loan until the system has saved money for all those years. The current monthly payments do not increase. Also, by the end of the 30 years, inflation will make those monthly payments relatively slight in comparison to avoided energy costs.

UTILITY FINANCE MECHANISMS

Another "painless" way to finance a solar add-on is to take advantage of utility finance programs. The Arkansas Public Service Commission has recently approved the Residential Conservation Service Program plan, which promotes energy conservation and renewable resource measures. Under this program, the major utilities in the state may offer financing for systems such as solar water heaters, space-heating systems, sunspaces or greenhouses, as well as insulation, caulking, weatherstripping, storm windows and doors. The homeowner may be eligible for no-interest/low-interest loans for those measures determined to be cost-effective following an audit of the dwelling. These loans may be repaid as part of the customer's utility bill, and in most instances, the cost of the energy saved will equal the monthly payment.

ENERGY SERVICE COMPANIES

It is possible that we will see the emergence of companies that provide energy services. These companies could be modeled on the energy service companies of Europe, and while aimed primarily at the commercial sector, they could also do business in the residential sector.

A typical energy service company operates in the following manner: the company selects a client, and promises to assume all energy costs for the client's operation. Assuming the client has not drastically improved energy efficiency within the last couple of years, the energy service company leases energy management equipment of various sorts to the client at a rate that is set at least 10 percent below current energy costs to the client.

If the energy management equipment increases the energy efficiency of the client by a substantial amount, the energy service company makes money on the difference between the energy costs it has assumed and the cost to the client of the leased equipment. In addition, the energy service company is eligible for the tax benefits accruing to the equipment itself, as well as the deductions for interest costs in the loan it has used to buy this equipment initially.

In the residential sector, the energy service company may be restricted simply to leasing solar equipment to homeowners. Although homeowners would not then be able to take advantage of tax benefits associated with solar equipment, the energy service company would set the lease rate low enough to correspond to expected energy savings, thus making for positive cash-flow financing. In addition, the energy service company would be required to maintain the equipment.

BANKS AND SAVINGS AND LOAN ASSOCIATIONS

Solar loan requests made through banks and savings and loan associations fall into one of three categories: home-improvement loans, permanent financing, or construction loans. Although it was not so long ago that lenders were dubious about financing solar homes and businesses, many are now in the forefront of the solar movement. The bankers are perceiving on the one hand a growing consumer demand for energy-efficient homes, and on the other, increased security for their loans based on manageable operating costs in the mortgaged property.

Bankers in Little Rock, Cabot, Jonesboro, and Russellville have enthusiastically financed new solar construction, and in some cases have actually sponsored it, to demonstrate to homebuilders and homebuyers the fact that a solar home need not be complicated, unattractive, or expensive.

ARKANSAS FARMERS' HOME ADMINISTRATION

The Arkansas Farmers' Home Administration (FmHA) has gotten so interested in solar that agency officials require all new projects to be bid as solar construction, and in nearly all cases, the solar bid is accepted. FmHA officials feel that given their financing abilities and the energy savings available from solar energy, it would be a waste of taxpayers' dollars **not** to use solar in their new construction.

QUALIFYING FOR A SOLAR LOAN

All these institutions recognize that the initial costs of solar homes and solar energy systems may increase the loan payment, and that the solar-home buyer's cash flow in the first few years may be slightly higher than that of the conventional homebuyer.

However, over the years, the cash flow should remain relatively stable, rising only with changes in tax and insurance rates and the increasing cost of whatever auxiliary energy source is used. On the other hand, the conventional homebuyer's cash flow is expected to rise rapidly, as the cost of energy continues to rise, and it will not be long before energy costs equal or exceed loan payments — a nightmare for lenders who see their loan security going out the window at that point.

In order to qualify for a solar construction loan, most builders need only prove that permanent financing for the proposed house is available, and that the plans for the house are logical. The builder's solvency, of course, is an issue just as it is in the case of a conventional construction loan, but there are no further constraints placed on the solar construction loan. In fact, as noted above, many lenders are actively trying to persuade their builders to go ahead with solar houses.

TAX-FREE BOND FINANCING

The Arkansas Housing Development Agency, which issues tax-free bonds for housing, offers a rebate for passive solar construction: $1,000 goes to the builder and $1,000 to the buyer. Currently, about 25 percent of any bond issue is set aside for new construction, and there are proposals afoot to set aside a portion of **that** money specifically for solar construction.

There is also interest in a proposal to create a state energy finance agency, which would have the authority to issue tax-free bonds to finance municipal and nonprofit solar projects, industrial solar equipment, commercial projects, and other activities that are currently starved for sources of financing.

TAX BENEFITS TO PURCHASERS OF SOLAR EQUIPMENT

Federal

1. Residential:
   40 percent tax **credit** on purchase of up to $10,000 worth of solar equipment. Includes active, passive, and photovoltaics, but does not include heat pumps.
2. Commercial:
   25 percent credit (10 percent investment tax credit plus 15 percent energy tax credit) for solar equipment (does not include passive).

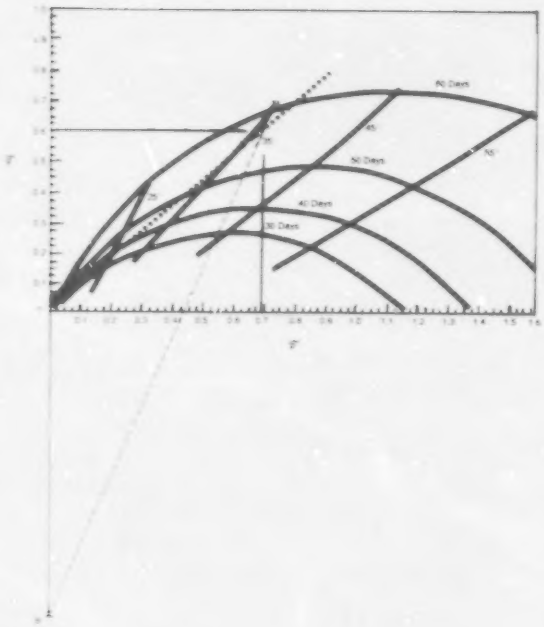
Arkansas

1. Residential and Commercial:
   100 percent state tax **deduction** on any and all renewable resource equipment used to heat or cool a building, or heat water.

APPENDIX 1

SIZING OVERHANGS

(The following design information is the result of work by Michael Utzinger, a registered architect and solar researcher at the Solar Energy Laboratory, University of Wisconsin, Madison. It first appeared in **Solar Age Magazine**, July, 1980.)

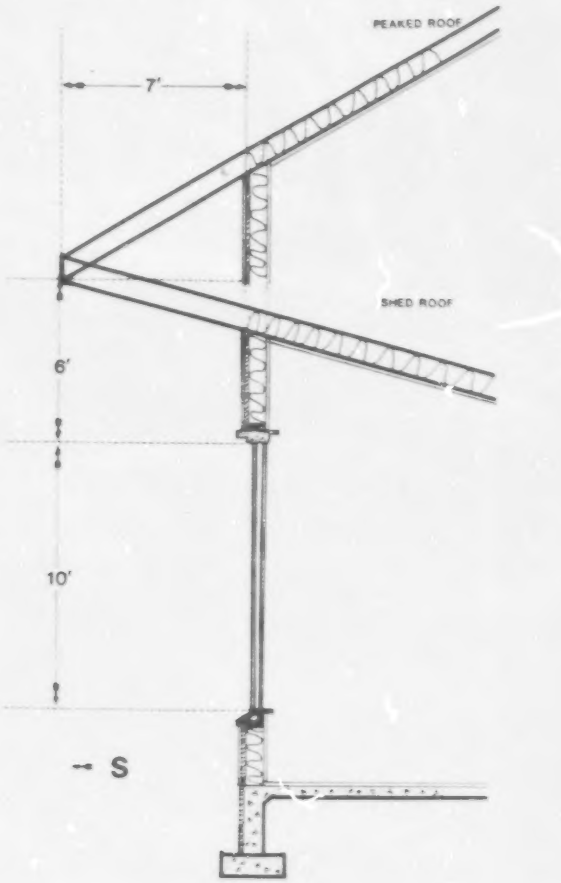


A method of sizing overhangs is shown here. From A Simple Method for Sizing Overhangs *by Michael Utzinger.*

The above illustration, called a nomograph, is a design tool that can be used to size the overhang for any south-facing vertical passive collector.

The data in this nomograph is applicable to a house facing due south. Generated from the relationship between the profile angle of the collector and the solar altitude, the nomograph allows a designer to choose when to allow sunlight into the house and when to keep it out. In this particular example, the designer can plan for a period of up to sixty days on either side of the winter and summer solstices.

The curved lines represent the desired number of design days, and the straight lines, numbered in degrees, represent north latitude. The vertical axis, g, represents the gap above the top of the collector, or window(s), and the horizontal axis, p, represents the horizontal projection of the overhang beyond the collector or window-wall. The terms g and p are expressed as a proportion of the collector



Drawing offers guide in sizing an overhang.

height. Thus, if the collector is 8 feet high and p is 0.2, the actual projection would be 8 × 0.2, or 1.6 feet beyond the collector.

The example worked out in the illustration assumes that the house is at 35° north latitude, or roughly the latitude of Little Rock. The designer has decided that the house will be totally shaded from April 22 to August 22 (60 days either side of the summer solstice) and completely open to the sun from October 27 to March 13, or 55 days on each side of the winter solstice.

In order to calculate the gap between the collector and the bottom of the overhang, and the projection of the overhang, the designer has drawn a dotted line from point T to a point at which a 55-day curve would intersect the line representing 35° north latitude. He has then drawn a line from point B to the point at which the 60-day curve intersects the 35° line. The line from T represents the winter shading angle; the line from B represents the summer angle. Where these two lines intersect, a vertical is dropped to the p axis, and a horizontal is extended to the g axis. Assuming the window height is 10 feet for the purposes of this example, p = 0.7, or 7 feet (10 × 0.7) and g = 0.6, or 6 feet.

The mathematical basis of the nomograph is "must" reading for those seriously interested in using it, and Utzinger explains it very well in the article from which the section is drawn.

You should note that even though the overhang provides protection from direct sunlight, diffuse and reflected radiation still enter the windows and contribute to heat gain during the summer.

APPENDIX 2

SOLAR CELL COMPANIES

ARCO Solar
9701 Lurline Avenue
Chatsworth, CA 91311
(213-998-0667)

Columbia Chase Solar Energy
55 High Street
Holbrook, MA 02343
(617-767-0513)

McGraw-Edison Company
Power Systems Division
P.O. Box 28
Bloomfield, NJ 07003
(201-751-3700)

Mobil-Tyco Solar Energy Company
16 Hickory Drive
Waltham MA 02154
(617-890-0909)

Motorola Semiconductor Products
5005 East McDowell Road
Phoenix, AZ 85008
(602-244-5459)

Optical Coating Laboratory, Inc.
15251 East Don Juan Road
City of Industry, CA 91746
(213-968-6581)

Photon Power
10767 Gateway West
El Paso, Texas 79935
(915-593-2861)

Sensor Technology, Inc.
21012 Lassen Street
Chatsworth, CA 91311
(213-882-4100)

Silicon Material, Inc.
341 Moffett Boulevard
Mountain View, CA 94943
(415-965-9890)

Silicon Sensors, Inc.
Highway 18, East
Dodgeville, WI 53533
(608-933-2707)

SES, Inc.
One Tralee Industrial Park
Newark, DE 19711
(302-731-0990)

Solar Power Corporation
5 Executive Park Drive
North Billerica, MA 08162
(617-667-8376)

Spire Corporation
Patriots Park
Bedford, MA 01730

Sun Trac Corporation
1674 South Wolf Road
Wheeling, IL 60090
(312-541-2095)

Texas Instruments Solar Group
13500 West Central Expressway
Dallas, Texas 77001
(214-238-2011)

Sollos, Inc.
2231 Carmelina Avenue
Los Angeles, CA 90064
(213-820-5181)

Solenergy Corp.
23 North Avenue
Wakefield, MA 01880
(617-246-1855)

Solec International
Two Century Plaza, Suite 484
2049 Century Park East
Los Angeles, CA 90067
(213-820-5181)

Solarex Corporation
1335 Piccard Drive
Rockville, MD 20850
(301-948-0202)

Edmund Scientific Company
552 Edscorp Building
Barrington, NJ 08007

BIBLIOGRAPHY

Langdon, *Movable Insulation,* 1980, Rodale Press, Emmaus, PA.

Mazria, *The Passive Solar Energy Book,* 1979, Rodale Press, Emmaus, PA.

Anderson, Balcomb, et al, *Passive Solar Design Handbook.* Vols. 1 & 2, 1980, prepared for the U.S. Department of Energy, DOE/CS-0127/1 & 2, available from National Technical Information Center, 5285 Port Royal Road, Springfield, VA 22161.

I.S.E.S., **Sunworld,** a journal of the International Solar Energy Society, Vol. 4, No. 1, 1980, Pergamon Press, New York.

McPhillips & Anderson, *The Solar Age Resource Book,* 1979, Everest House, NY.

Anderson & Riordan, *The Solar Home Book,* 1976, Cheshire Books, Harrisville, NH.

Butti & Perlin, *A Golden Thread: 2500 Years of Solar Architecture and Technology,* 1980, Van Nostrand/Reinhold, NY.

Beckman, Klein, and Duffie, *Solar Heating Design by the F-Chart Method,* Wiley & Sons, NY, 1977.

U.S. Department of Housing and Urban Development, *Installation Guidelines for Solar DHW Systems in One and Two-Family Dwellings,* 1980, U.S. Government Printing Office #625-072.1845.

McCullagh, *The Solar Greenhouse Book,* Rodale Press, Emmaus, PA.

Olgyay and Olgyay, *Solar Control and Shading Devices,* Princeton University Press, 1957, Princeton, NJ.

Solar Age Magazine, Solar Vision, Inc., Harrisville, NH, January, 1981.

Davidson & Skiles, *The Office of Human Concern Solar Heater,* revised 1980, Office of Human Concern, Rogers, AR.

Turner & Battle, *Solar Radiation for the State of Arkansas,* 1980, University of Arkansas, Fayetteville, AR.

U.S. Department of Housing and Urban Development, *Protecting Solar Access for Residential Development,* American Planning Association, 1313 East 60th Street, Chicago, IL 60637, 1980.

Citizens' Energy Project, *The Citizens' Energy Directory,* 2nd Edition, Citizens' Energy Project, 1110 Sixth Street NW, Washington, D.C. 20001.

Solar Ponds and Their Applications, SERI, TP-733-617, March, 1980.

Solar Ponds For District Heating & Electricity Generation, SERI, TP-733-759, July, 1980.

SOLAR PHOTOVOLTAIC CELL PUBLICATIONS

Sunlight to Electricity (Prospects for Solar Energy Conversion by Photovoltaics) by Joseph A. Merrigan. MIT Press, Cambridge, MA, 02142. (1975, 163 pages).

The Dawning of Solar Cells by David Morris. Institute for Local Self-Reliance, 1717 Eighteenth Street, NW, Washington, D.C. 20009. (1975).

Solar Cells journal from Elsevier Sequoia S.A., P.O. Box 851, CH-1001 Lausanne, Switzerland ($160/year, quarterly).

DOD Photovoltaic Energy Conversion Systems Market Inventory and Analysis by the BDM Corporation, McLean, VA. (July, 1977).

Solar Energy: A Comparative Analysis to the Year 2000 by the Mitre Corporation; METREK Division, McLean, VA. (March 1978; report #MTR-7579).

3 Active Solar Energy

Successful Solar Buying

INTRODUCTION

Making a decision to install solar energy in your home is one thing; putting tha decision into actic:n is quite another. Because the industry is still new, everyone connected with it still has plenty to learn. This pamphlet has been written so that you, the consumer, can avoid painful and expensive mistakes in purchasing your solar equipment.

How do you make a wise decision? One suggestion is: Go slowly and don't let unfamiliar terms and equipment confuse or scare you. You do not have to understand all of the mechanics and theory.

You should know enough about the potential problems of solar installation before you turn the job over to a contractor. That way you won't be paying for the installer's learning time. You should know enough to recognize the pitfalls in such areas as heat exchangers, thermal storage, heat-loss resistance (R-value), sunlight, active and passive systems, etc.

SELECTING THE CONTRACTOR

Consult several solar contractors before making a selection. While time-consuming, it is essential in obtaining quality work at a fair price.

Consider the contractor's location. A local office is important in providing a prompt response to service calls. A local business owner will be interested in protecting his or her local reputation.

Know your contractor before you sign a work order. Sometimes a recommendation from a friend who has installed a solar system is best. Ask if the installation was done properly and what kind of after-the-sale service record the firm has.

Determine the contractor's qualifications. Experience in installing solar systems as well as experience in closely-related fields such as plumbing and heating is desirable. The contractor's support from the manufacturer of the solar equipment is also important and should be verified by a certificate of training or by supervision or inspection of the job by a representative of the manufacturer.

Establish the contractor's local reputation. Request references and check on satisfaction with the installation, the amount of service that has been required, and the promptness of response to requests for service. It's a good idea to inspect some installations if possible, and talk to owners.

Require an Owner's Manual. The manufacturer should provide a clear and complete manual, which the contractor should review with the homeowner.

Pay particular attention to any maintenance

responsibilities assigned to the homeowner.

Be sure you know who is responsible for obtaining and paying for any necessary local permit.

Be sure you know specifically who will service the system.

THE WRITTEN CONTRACT

A written contract is a **must**. Read and study the written contract to get a clear understanding of the contract before signing it. Never sign a contract unless all blanks have been filled in completely. Keep a copy of the contract for your own records.

Obtain a written cost quote on the complete job. Consider the cost along with the other factors, including specifications with the brand names and size of the materials, and the method of payment.

Remember you can cancel a home solicitation agreement within three business days, if the purchase price exceeds $25 and the seller was not invited to your home.

There are different kinds of contracts. Learn what they are and what they mean. Don't be pressured into signing a contract. Take your time to consider the agreement and what responsibilities and liabilities you will assume if you sign. Never sign a contract that has not been signed by the other party.

Don't be afraid to ask questions. Some questions to ask are:

How do I determine whether or not my present or future home is a good candidate for solar systems?

What modifications need to be done to my house to use this system?

What information do I use to determine which system is best for me?

How much will the system cost me?

How long will the system last?
How long do most systems last?

Will there be maintenance costs? Time required of me?

How long has the firm been in business?

How many solar systems has the firm sold?

Who will install the system? Are parts easily obtainable?

Who is qualified in my area to install, build and design systems?

Will the solar system be covered by my home insurance agent?

Are there specific tasks the consumer will have to perform?

Will the system be equipped with monitoring equipment so that the performance can be checked from time to time?

Will the system operate without interfering with the operation, replacement, maintenance, etc., of existing equipment?

Does the system meet industry standards?

Will the collectors have an obstructed view of the sun?

Is there sufficient area to accommodate solar collectors and heat storage?

WARRANTIES: HOW THEY AFFECT YOUR PURCHASE

Examine the warranty carefully. What are its limitations? Solar components are like stereo components — some work well together, others do not.

A warranty and a guarantee are the same thing: a promise by manufacturers or sellers to stand behind their products.

They must live up to the written promises and, in some instances, even go beyond what is written. There are two legal requirements governing warranties for solar systems: the federal Magnuson-Moss Warranty Act and the Uniform Commercial Code.

You should know who is responsible for honoring the warranty — the installer, the dealer or the manufacturer. Know the financial arrangements, such as contractor's bonds, to assure that the warranty will be honored. Remember, a warranty does not guarantee that the company will remain in business.

AFTER INSTALLATION

Before and during installation, check to be sure the system and its components are exactly as you have ordered. Do not accept them otherwise.

Check to see that all indoor and outdoor solar system piping is insulated.

When the installation is complete, have the installer test the system for leaks or malfunctions.

Review the system with the installer to make sure you understand its operation and what, if anything, is required by you for its operation and maintenance.

Be sure the installer supplies you with a manual that contains this information.

The installer should review the manual with the homeowner. Pay special attention to any maintenance responsibilities assigned to the homeowner.

Thermometers should be placed on the pipes of ducts going to and from the collector to monitor the system's heat gain; another thermometer can be placed in the storage area to measure how much heat is retained.

Check to see if all moving parts and switches are functioning quietly.

Get a system tune-up with the installation: this consists of adjusting pressure and removing air from pipelines to ensure proper water flow.

Note the specifics not included in the warranty or service contract.

Ask for instructions on how to correct problems. This way you can make sure you understand the system's operation.

The completed system should operate normally for at least a week and then be inspected by the installer.

Be sure the collectors face as true south as possible and are unshaded.

The collector, heat exchangers and storage units of a solar energy device and their installation should be warranted for a period of not less than two years.

The remaining components of the solar energy device and their installation should be warranted for a period of not less than one year.

The seller should disclose the warranty responsibility of each party.

Get a clear understanding of whom you should contact if a problem arises with the system.

FOR MORE INFORMATION

Consult your library for these publications:

Solar Age magazine, Harrisville, New Hampshire, 03450.

"Consumer Protection Issues in Energy", U.S. Department of Energy, Office of Consumer Affairs, Washington, D.C., 20585.

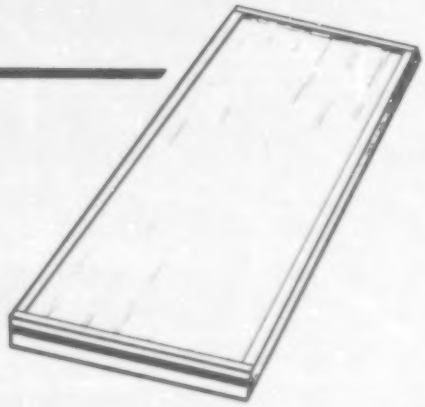
"Solar Heating and Cooling of Residential Buildings, Sizing, Installation and Operation of Systems", Solar Energy Applications Lab, Colorado State University USGPO Stock No. 003-011-00085-2, October, 1977.

The Arkansas Consumer Protection Office is the place to go to with a complaint.

You may contact the Arkansas Consumer Protection Office by calling 371-2341 if you live in Pulaski County. If you live outside Pulaski County, the toll-free number is 1-800-482-8982. Or you may write the Consumer Protection Division:

Consumer Protection Division
Office of the Attorney General
Justice Building
Little Rock, Arkansas 72201

Solar Air Heaters



FUNDAMENTALS

Solar air heaters are simple devices that utilize solar energy to help heat buildings in winter. Air heaters are probably the lowest costing and most efficient solar device you can build to reduce home energy costs.

The basic principles of all solar air heaters are the same. A black-painted piece of metal, called the **absorber,** is mounted within a shallow frame. Next, the frame is covered by a sheet glazing (glass or fiberglass), which faces south. As sunlight passes through the glazing and strikes the absorber, it causes the black absorber to get hot; much hotter than it would if there were no glazing. Air is drawn from inside the house, across the absorber, where it picks up heat, and then back into the house. During its circuit, the air will rise in temperature anywhere from 20° F to 30° F. The frame, the absorber, and the glazing make up what is called a **solar air collector.**

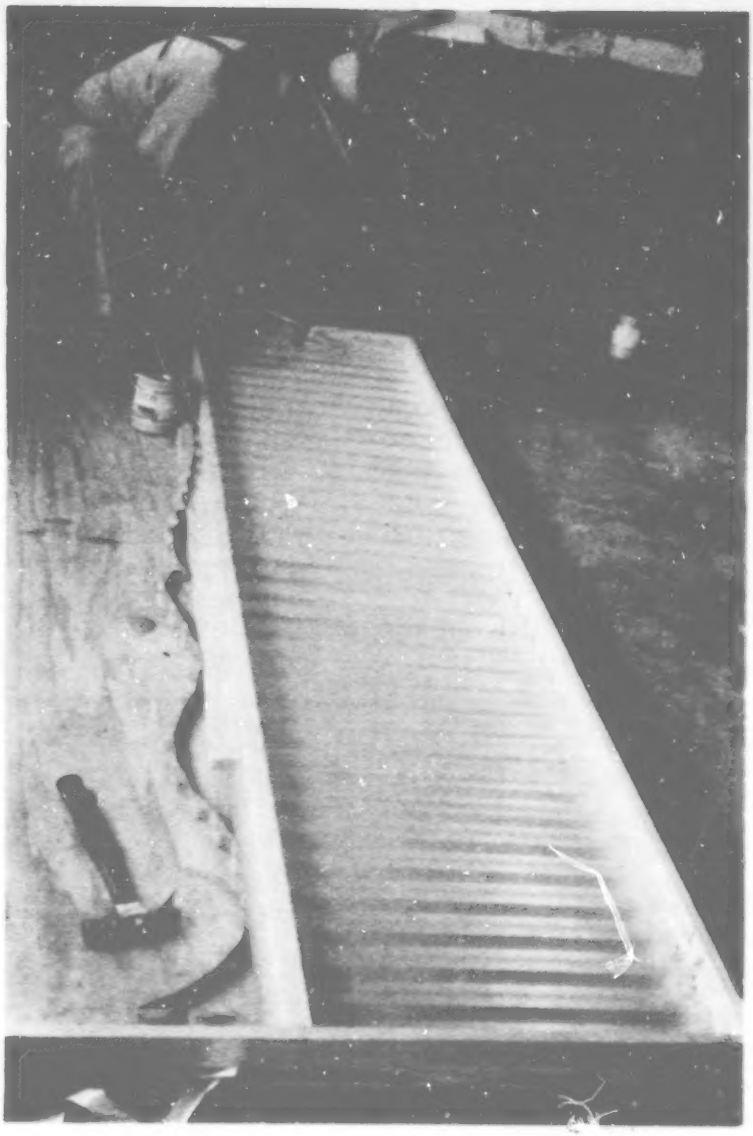
Most solar air heaters built in Arkansas are active collectors; that is, they use an electrical fan (blower) that is thermostatically controlled to blow air across the absorber when it is hot enough to produce heated air. Solar air heaters can also be passive, relying only on the principal of **gravity convention** or **thermosiphoning,** which is the natural movement of air due to differences in temperature. As the sun heats the absorber, the air around it gets hot, causing it to expand and rise out of the collector and into the house through an upper vent, thus drawing cooler room air into the collector through a lower vent. Although active solar air heaters require electricity to operate, they are still very simple and generally will deliver more BTU's per dollar than passive solar air heaters.

Solar air heaters can be further categorized as either **modular** or **site built.** Modular solar air heaters refer to small (usually 4′ x 8′) units that provide heat for a room that is used in the daytime. Site-built solar air heaters operate the same as modular air heaters, but they are larger (8′ x 8′ or bigger) and are more economically built in place at the site. Typically, site-built solar air heaters cover most of the south wall of a home to provide a large portion of the heating needs. Since large amounts of heat are produced, ducts are often used to distribute the heat to various rooms, and sometimes thermal storage systems, such as rock beds, are utilized to store excess heat for use at night and on cloudy days.

New Life Farm, Inc. (Drury, MO 65638) has built many site-built solar air heaters throughout the Ozarks.

Their manual, "Simple Solar Air Heaters," by Ron Hughes, ($3.50) is an excellent reference for learning the many different possibilities for adapting air heaters to homes and other buildings.

The Office of Human Concern (OHC) of Rogers has conducted twenty solar air heater workshops for individuals, vo-tech schools and community agencies throughout Arkansas. The 4′ x 8′ collector shown here is being installed by local residents onto a community center in Gravette.



Construction of the O.H.C. solar air heater requires only simple carpentry skills. In the photo above, the absorber (aluminum roofing) is being fitted within the collector frame during a construction workshop in Blytheville.

MODULAR SOLAR AIR HEATERS

Modular air heaters have been ideal for the purposes of several community agencies in Arkansas who have built and installed over 100 units on the homes of elderly, low-income families during the past two years.

The first modular solar air heater in Arkansas, and the standard by which most others have been built, was developed by Joel Davidson and Bill Brown of the Office of Human Concern (OHC) in Rogers. They saw a need for air heaters as the next logical step to reduce fuel consumption in homes that had already been weatherized. Their objectives were to design a low-cost solar air heater that could be:

1. Built in quantity with simple carpentry tools and skills.
2. Assembled easily and cheaply by using standard 4 x 8 components for the glazing, absorber, and backing.
3. Delivered and installed in less than a day.
4. Completely automatic.
5. Durable enough to last at least 10 years without maintenance.

Figure B-1 illustrates the construction of the collector, which is mounted either vertically or horizontally against the south wall of the house. The area between the absorber and the glazing is a dead air space which is vented in summer by thermostatic vents to prevent overheating. The air flows through a 1½" x 24" air gap behind the corrugated aluminum ab-

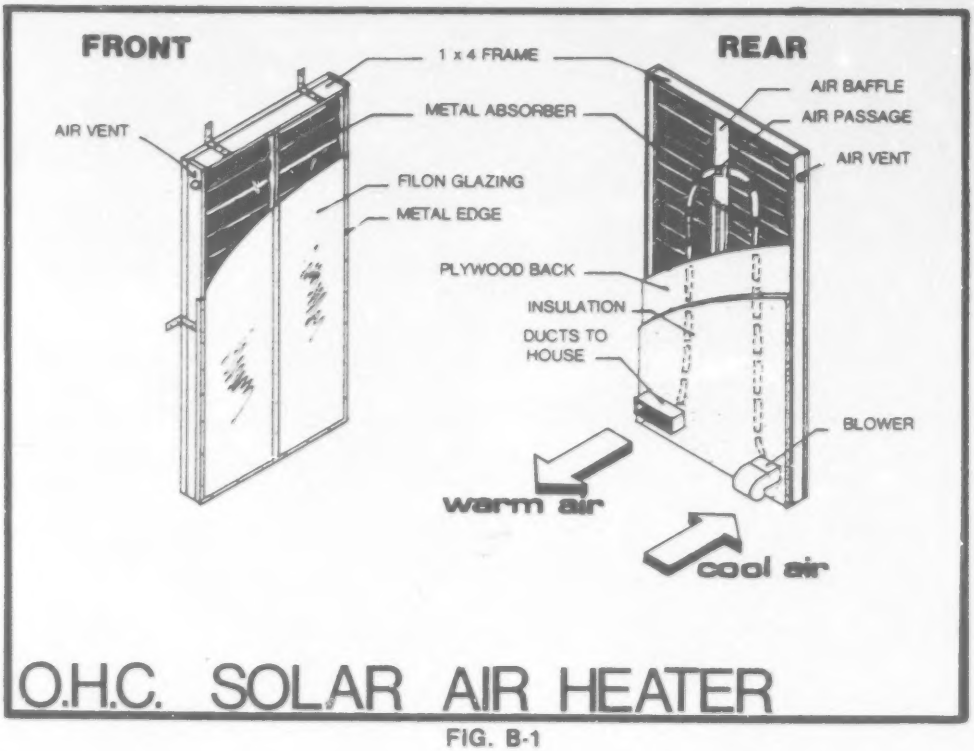


FIG. B-1

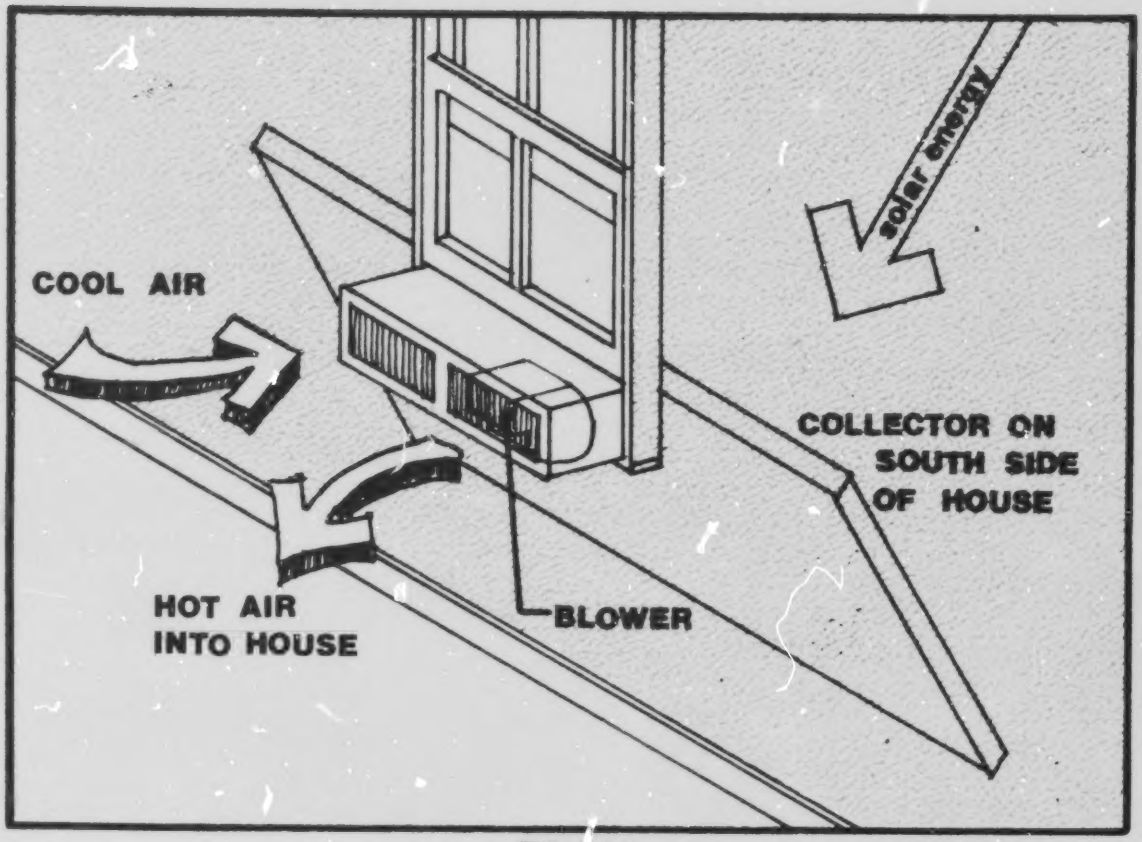


FIG. II-2

sorber. (The depth of 1½" includes the depth of the corrugations.) A 200 CFM squirrel cage blower pushes the air in a U-shaped path around a center baffle for a total air run of 16 feet.

Jim Free, of the Crowley's Ridge Development Council in Jonesboro, has designed a variation of the OHC collector. Air is blown both in front of and then behind the absorber for a total run of 32 feet. To compensate for the increased distance of air flow, the air gap has been increased to about 1-½" on each side of the absorber. Jim recommends a 200 to 350 CFM blower.

Another modular solar air heater based on the OHC model has been developed by Peter Scholls of the Crawford-Sebastian Community Development Council in Van Buren. This unit is identical to the OHC version except that a 10" propeller-type duct fan instead of a squirrel cage blower is used. The duct fan has the advantage of fitting flush within the wall for more quiet and unobtrusive operation. Since propeller-type fans have less power than squirrel cage blowers to force air through the collector, the duct fan requires a higher CFM rating of 425 to 600.

Each of these three collectors costs about $110 if the components are bought at wholesale prices and about $150 if the materials are bought at retail prices, as they would be for homeowners who wish to build one

or more units for themselves. A free, illustrated, step-by-step manual on construction, operation, and performance of the OHC collector is available from the Office of Human Concern, P.O. Box 756, Rogers, Arkansas 72756. A similar construction guide of Jim Free's collector design is available from the Crowley's Ridge Development Council, Jonesboro, Arkansas.

Larry Bueg, of the Energy Center, Inc. in Lowell, recently designed a 4′ x 8′ modular solar air heater that is quite different from any built in Arkansas. As shown in Figure B-2, this unit mounts directly into the lower part of a south window, eliminating the time and expense of putting ducts through the wall. Instead of being mounted flush against the wall, this collector has brackets which can adjust the collector to the optimum angle for solar collection in winter.

The absorber, which also serves as the insulation and back of the collector, is a 4′ x 8′ x 1″ sheet of rigid, high-temperature fiberglass. Black aluminum foil covers the fiberglass to serve as the heat-absorbing surface. Galvanized steel baffles create a serpentine air flow in front of the absorber. Total length of air run is 32′, with an air gap of 2″.

The manifold that projects through the window is divided into two halves, one side serving as the air intake into the collector and the other side housing a small squirrel cage blower. Unlike the arrangements in the previously mentioned collectors, this blower pulls instead of pushes air through the collector.

It was found that much more air is delivered to the room when the blower is mounted on the delivery side of the manifold rather than the intake side.

The collector is framed in sheet metal with a fiberglass glazing, making it very lightweight and weatherproof. In summer, the unit can be easily removed from the window and stored in the garage or, better yet, can be utilized as a solar food dryer. The collector can be fitted to a cabinet with vertically arranged screen trays upon which the food is placed. Solar heated air is blown through the cabinet, thus drying large quantities of food very rapidly. Arkansas families who traditionally use canning as a means of preserving food could instead use such a device to solar dry their food, saving much time and energy. Also, dried foods have superior taste and nutritional value over canned foods.

PERFORMANCE

There is an urgent need to compare the performance of these collectors in side-by-side tests so that effective improvements can be made in their design. To date, all the design criteria have been based on research and demonstration projects by the San Luis Valley Solar Energy Association (P.O. Box 1284, Alamosa, CO 81101) and the Small Farm Energy Project (P.O. Box 736, Hartington, NB 68739). These two non-profit organizations have developed the rules-of-thumb for solar air collector design that have been used successfully throughout the country.

Although precise scientific measurements have not been made to compare performance among the air heaters, studies have been done to assess the general effectiveness of

the OHC collector. The following is an excerpt from the OHC air heater manual that describes the results of tests conducted from October 10, 1979 to February 26, 1980:

"Ten homes occupied by low-income elderly people in Benton, Carroll and Madison Counties were fitted with solar air heaters in September of 1979. Seven of the homes were heated with natural gas and three of the homes were heated with propane. (Wintertime) fuel consumption for each home from 1977 to 1980 was obtained from fuel suppliers (Arkansas Western Gas and Sungas).

In the test homes, the dollar savings (caused by the air heaters) ranged from 6.3% to 13.44%, with an overall average of 9.87%. It is expected that this figure will increase with the use of the larger blower (200 CFM) and the addition of an adjustable thermostat that will extend the daily hours of operation."

The decision to change to a 200 CFM blower was a result of the tests conducted in January of 1980 by Dr. Thomas Rokeby, a consulting engineer who is director of the solar poultry house project at the University of Arkansas in Fayetteville. He tested several different sizes of blowers to determine air flow characteristics of the air heater and concluded that the larger blower would increase heat production by about 38%.

More tests were performed on the OHC air heater in December of 1980 by Russ Garton and Steve Metcalf, graduate students in mechanical engineering at the University of Arkansas in Fayetteville. They determined the average efficiency of the collector to be 48.5%, which is very good when compared to similar air heaters built by the Small Farms Energy Project and others.

For Little Rock, a vertical south-facing surface will receive an average of 152,140 BTU/ft² total solar radiation during the heating season (November to March). Therefore, a collector of 32 square feet and 45% efficiency would deliver:

$$152{,}140 \text{ BTU/ft}^2 \times 32 \times .45 = 2{,}190{,}816 \text{ BTU}$$

The value of 2,190,816 BTU's of heat for houses that use electricity, natural gas or propane to heat their homes in 1981 is:

Electricity
2,190,816 BTU = 641 Kilowatt/Hours
At 6¢ per KWH, you save
.06 × 641 = $38.46

***Natural Gas**
2,190,816 BTU = 2.12 MCF
At 3.50 per MCF, you save
2.12 × 3.50 × 1.30 = $9.65

***Propane Gas**
2,190,816 BTU = 23.8 GAL
At .80 per gallon, you save
23.8 × .80 × 1.30 = $24.75

*Whereas electrical heating is 100% efficient, you only get about 70% of the BTU's available in each unit of gas (the rest goes up the flue). So an efficiency factor of 1.30 is included in the value of each unit of gas that is saved by solar energy.

If you spend $150 to build an air heater and take the 40% federal tax credit, the actual cost is only $90. With prices of electricity, natural gas and propane rising dramatically, an investment in an air heater will pay for itself in two to five years.

DESIGN METHODS

The basic rules of the thumb for designing solar air heaters are:

1. The baffle layout in the collector should be such that no single **air run**, the distance between the inlet and the outlet, exceeds 32 feet.

2. The "delivered" air flow should equal 3 CFM per square foot of collector. The **delivered** (or actual) air flow is the fan's rated capacity (CFM) after it has gone through the collector. This capacity will be less than the **free air** rating of the fan because of the resistance encountered in the collector. The average air flow reduction, called the **static pressure drop**, across a typical solar air heater is rated at .5 on an instrument that measures pressure change in inches of water in a column. Most fan and blower CFM ratings are given for both "free air" conditions and over a range of pressure drops.

For example, the delivered air flow through a 32-square-foot collector should be: 3 CFM × 32 = 99 CFM. Since it is assumed that the pressure drop will be about .5 inches, the rating for the fan at a pressure drop of .5 inches should be at least 99 CFM. Most squirrel cage blowers with a free air rating of 200 CFM will have a delivered air flow of 100 CFM at a pressure drop of .5 inches.

3. The air gap is a function of the air flow (cubic feet per minute) and the air velocity (feet per minute). The assumed optimal air flow is 800 FPM (Feet Per Minute). Divide the free air CFM rating by 800 FPM to get the area (in square feet) of the air gap cross-section. The gap is then found by dividing the cross section area by the width of the collector air way in one direction of air flow.

For example, the free air rating for a 32-square-foot collector was determined to be 200 CFM. So:

200 CFM ÷ 800 FPM =
.25 square feet or 36 square inches.

Since the air way width is 24 inches, the gap is

36 ÷ 24 = 1.5 inches.

If corrugated roofing is used as the absorber, as in the OHC collector, the depth of the corrugations must also be counted as part of the air gap.

Arkansas Energy Future

Solar Hot Water

ACKNOWLEDGMENT

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INTRODUCTION

From the Greek Helios through the Roman Sol and American Indian sundances on the solstices, the sun has been revered and respected as our primary energy and life source. The twentieth century has seen industrialists, farmers and homeowners renew that affinity by seeking to use solar energy for space or process heat and other power uses.

The sun provides the essential energy to support all plant, animal and human life; but as conventional fuel supplies dwindle, a major use of solar energy will be support of man's industrialization. The most successful applied uses of solar energy to date have been solar thermal systems, which provide space heat, service and domestic hot water or industrial process heat. Solar domestic hot water is one of the simplest and most viable.

The purpose of this manual is to provide basic information on designing and installing a domestic water-heating system by using well-established designs and off-the-shelf component parts. The essential skills required for installing a solar water-heating system include plumbing, carpentry, roofing and some wiring ability. Any special considerations that your solar system requires will be noted, but it's assumed that the information on those basic techniques (soldering sweat-joints, framing for collector arrays, etc.) can be obtained from vocational-technical and trade schools or from general texts in those areas.

ARKANSAS PLUMBING CODE

The Arkansas Solar and Hydronic Heating Code is Chapter 16 of the Arkansas Plumbing Code. Its provisions are enforced by the Plumbing Division of the Arkansas Department of Health. The Code requires that any person who installs solar hot-water systems and other applicable hydronic heating systems hold a solar mechanic's license.

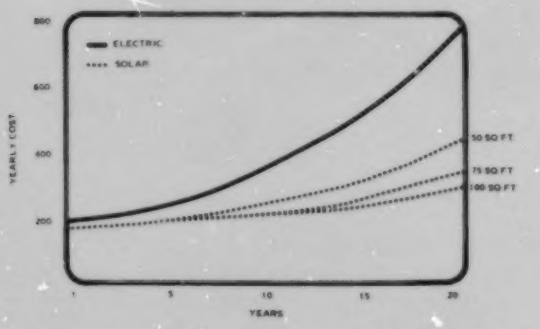
As an exception to this provision, a licensed master plumber may install systems that are certified by the Solar Rating and Certification Corporation (SRCC). Plumbers may not install other systems without first obtaining a solar mechanic's license.

The Health Department issues those licenses as the Code allows, much as it administers plumbing and gasfitters licenses.

The Code also provides for minimum materials and workmanship standards and assures a minimum performance by addressing system design requirements.

The Arkansas Energy Office and the Plumbing Division of the Health Department have additional information for licensee applicants, plumbers and consumers. Call the Energy Office at 371-1370 or the Plumbing Division at 661-2642.

SOLAR WATER HEATING VERSUS ELECTRIC OR NATURAL GAS WATER HEATING



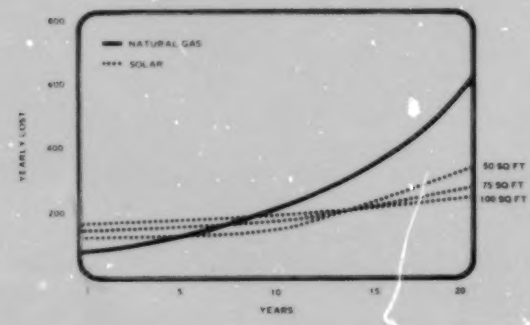
Charts graphically represent a cost comparison between solar water heating and either electric or natural gas water heating.

The costs each year for the conventional systems are comprised of fuel costs (projected) and the yearly depreciation of the water heating unit's initial cost.

The costs each year for the solar systems, in sizes of 50 square feet, 75 square feet, and 100 square feet, are comprised of the costs of backup fuel, and the yearly depreciation of the solar water-heating system's initial cost.

The fuel costs are conservatively based on an average annual increase of 11.9 percent for natural gas and 8.6 percent for electricity.

Increases in later years in costs are totally attributable to increasing fuel costs.



ARKANSAS' CLIMATES

Arkansas' weather patterns are as fickle and unpredictable as weather patterns anywhere. On October 9, 1980, Eureka Springs recorded a high of 94° F. Seventy miles southeast, Gilbert recorded 15 degrees only three weeks later. Arkansas' climates are so diverse that the heating requirement in Bentonville, Harrison or Gilbert can be nearly twice the heating requirement of Texarkana, Crossett, or Eudora in the same winter. Because of this wide range of heating loads, it is impossible to generalize about a statewide solution to heating needs. Heating systems must be matched to a particular load in a particular climate. Similarly, in the design of a solar flat-plate collector system, one must carefully consider the severity of the weather conditions in which it will perform. Systems that employ water as a direct heat-transfer fluid may be substantially more troublesome and less reliable in the Ozarks than in the Gulf Plains area, because of the greater likelihood of freeze damage. Systems that use some energy to accomplish freeze protection would be better suited for Texarkana, where they would incur parasitic losses only about 40 days a year, than in Gilbert, where subfreezing days often number 100 or more each year.

The amount of sunlight available in Arkansas is a fairly consistent quantity throughout the state. The amount available varies less than 10 percent from the best to the worst areas in every month except January (when northeast Arkansas gets 16 percent less sun than southwest Arkansas). Despite the temperature variances over the year, the annual difference in the sunniest and least sunny areas varies only slightly over 3 percent. This statistic is, of course, not applicable to quite a few mountain-valley areas, where valleys receive substantially less sunshine.

EFFECT OF WEATHER ON COLLECTOR PERFORMANCE

Benton County has a 4034 heating degree-day climate. Columbia County, only 225 miles to the south, averages 2468 heating degree-days per season. That's an average of about 10° F temperature difference on a seasonal average. That 10° F temperature difference will mean a 5 to 10 percent difference in efficiency for similar systems in north and south Arkansas under winter conditions.

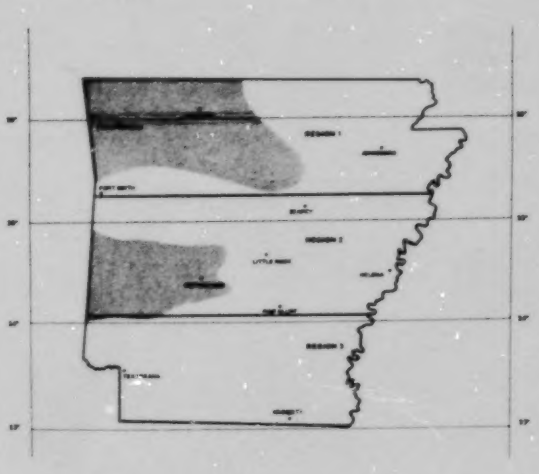
MONTHLY INSOLATION ON SOUTH-FACING SURFACES

45° TILT

(BTU/FT²/MONTH)

	Region 1 Fayetteville	Region 2 Little Rock	Region 3 Texarkana
January	33852	34162	36952
February	36596	38976	37464
March	44113	44485	45973
April	46110	46440	45450
May	49445	45942	50437
June	51335	49290	47100
July	51460	50437	48577
August	52018	50995	49383
September	43350	43710	44850
October	43400	45663	45632
November	33900	35940	37050
December	30845	31930	31868

A collector system working at 30 percent efficiency collects only 83 percent as much usable energy as one working at 35 percent efficiency. Because flat-plate collectors will have a lower efficiency in the colder temperatures of north Arkansas, it may be necessary to size the collector area 10 to 15 percent larger than a similar home might need in south Arkansas.



Extrapolated from *Solar Radiation for the State of Arkansas*, University of Arkansas, Turner/Battle.

SOLAR RADIATION

Solar radiation is also known as insolation — **IN**cident **SOL**ar radi**ATION.**

On a clear day, when there are no clouds, most of the solar radiation is beam or direct insolation. On totally overcast days, the insolation is completely diffuse and reflected radiation. Flat-plate collectors do not distinguish between types of radiation; therefore, when the total radiation is sufficient to begin the thermosiphoning or start the pump, the diffuse and reflected components are useful to the flat-plate collector as well as the beam radiation.

The two basic relationships between the positions of the earth and the sun are the altitude, or the angle from the horizon to the sun, and the azimuth, or the angle measured from true south and the sun's position. A solar collector's performance varies as the sun's azimuth varies hourly, and as the altitude varies seasonally. It is most efficient at noon and perpendicular to the sun, least efficient at daybreak and sunset and when the sun's rays are received farthest off of square.

ARKANSAS DEGREE-DAY FIGURES BY COUNTY

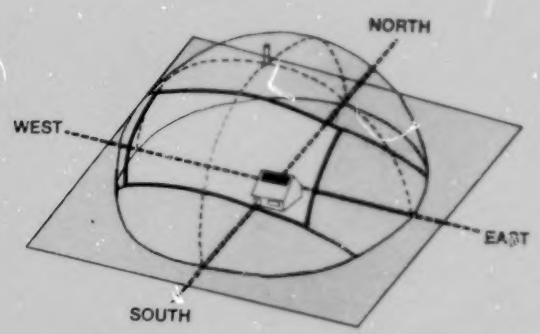
County	Normal 30-Year Annual Heating Degree Day	District Heating Factor
Arkansas	3061	.77
Ashley	2488	.62
Baxter	3852	.96
Benton	4034	1.01
Boone	3884	.97
Bradley	2577	.64
Calhoun	2639	.66
Carroll	3787	.95
Chicot	2601	.65
Clark	2838	.71
Clay	3678	.92
Cleburne	3467	.87
Cleveland	2627	.66
Columbia	2468	.62
Conway	3131	.78
Craighead	3352	.84
Crawford	3587	.90
Crittenden	3337	.83
Cross	3354	.84
Dallas	2627	.66
Desha	2713	.68
Drew	2694	.67
Faulkner	3049	.76
Franklin	3199	.80
Fulton	3959	.99
Garland	2729	.68
Grant	2968	.74
Greene	3538	.88
Hempstead	2928	.73
Hot Spring	2954	.74
Howard	3025	.76
Independence	3780	.95
Izard	3816	.95
Jackson	3242	.81
Jefferson	2800	.70
Johnson	3281	.82
Lafayette	2564	.64
Lawrence	3400	.85
Lee	3165	.79
Lincoln	2757	.69
Little River	2782	.70
Logan	3188	.78
Lonoke	3250	.81
Madison	3862	.97
Marion	3868	.97
Miller	2659	.66
Mississippi	3386	.85
Monroe	3200	.80
Montgomery	3328	.83
Nevada	2749	.69
Newton	3877	.97
Ouachita	2707	.68
Perry	3137	.78
Phillips	3037	.76
Pike	3177	.79
Poinsett	3508	.88
Polk	3105	.78
Pope	3163	.79
Prairie	3147	.79
Pulaski	3354	.84
Randolph	3662	.92
St. Francis	3144	.79
Saline	3281	.82
Scott	3166	.79
Searcy	3914	.98
Sebastian	3336	.83
Sevier	2855	.71
Sharp	3800	.95
Stone	3847	.96
Union	2645	.66
Van Buren	3523	.88
Washington	3839	.96
White	3154	.79
Woodruff	3221	.81
Yell	3128	.78

The diffuse and reflected components compose about 30 percent of the radiation in clear months and about 40 to 45 percent in the spring and fall rainy seasons. Because a flat-plate collector makes use of diffuse and reflected radiation and because it achieves the temperatures needed at a fairly low cost, this is a logical choice for domestic hot water (DHW).

SITING AND ORIENTING THE COLLECTOR SYSTEM

All new home sites can be landscaped and built to make maximum use of solar benefits. Not every existing home site is appropriate for solar use, but among sites with a general exposure to the south, collectors can be effective even if they do not face due south. Due south (6½° east of magnetic south for Little Rock, 5° east of south for Blytheville, 7° east of south for Eureka Springs) will yield the best harvest of British thermal units. However, collectors facing as much as 30° either side of true south will collect 90 percent maximum available energy. The solar collector's efficiency drops to 72 percent of the total available for true southeast and southwest and to 31 percent for east and west. If your roof's ridgeline runs 30° off an east and west orientation, you can simply oversize your collectors by 10 percent from the original sizing calculation, and it should work fine. When you have a choice, orient the collectors as close to south as possible to minimize your costs.

Roof brackets can be fabricated by your local welder for obtaining the desired compound angle for roofs that are off south and off of the desired tilt angle substantially.



Solar Window

SHADING

Any collector that is shaded at all between 9 a.m. and 3 p.m. is not harvesting the energy that it should collect. The surest way to assure that your collectors will not be shaded is to photograph or at least observe the shadows cast on the site on December 21, when the sun is lowest in the sky. The site should be free of all shadows from 10 a.m. to 2 p.m. An ideal site would receive full sun all day every day but full solar access for those four midday hours should be considered a minimum standard for collector siting.

TILT

The sun's altitude is constantly changing from a maximum angle of 90° minus latitude plus 23½° on the summer solstice, June 21, to a minimum angle of 90° minus latitude minus 23½° on the winter solstice, December 22. Arkansas' latitudes range from 33° N to 36½° N.

In Mammoth Springs or Piggott, the noon sun is just under 30° altitude from the horizon on the winter solstice.

The maximum altitude on that day is 34° at noon in El Dorado.

The summer altitude angles are 77° and about 80.5° for El Dorado and Mammoth Springs, respectively, (and all towns worldwide at that latitude).

Because the sun's altitude is making a 47° swing from solstice to soltice, an optimum tilt angle, for a stationary flat-rate collector must be determined. The best tilt angle for year-round water heating is the latitude angle.

In south Arkansas, that's 33°, or about the angle of a roof with an 8 and 12 pitch. In north Arkansas, the optimal angle is about the angle of a 9 and 12 pitch.

Systems that are also used for space heating should be tilted to latitude plus 10°. In central Arkansas, that's 45° or a 12 and 12 pitch, in builders' terms.

How much will another tilt angle penalize the system's performance? A tilt of 20° off the recommended angle should not reduce performance by more than 10 percent. That reduction in energy gained can be offset by using

reflectors or adding areas to the collector array.

A frame can be built, which will support the collectors at an angle steeper than the roof. Wind loads on bracketed collectors can add as much as 10 pounds per square foot to the roof load; so, be sure to consider this as you inspect framing for suitability of roof-mounted installations.

COLLECTOR INTERCEPTION EFFICIENCY FOR VARIOUS MISALIGNMENTS

Azimuth Angle Off Of South	Percent of Maximum Solar Energy Intercepted*
0°	100.0
5°	99.6
10°	98.5
15°	96.5
20°	94.0
25°	90.8
30°	86.6
35°	81.9
40°	76.6
45°	70.7
50°	64.3

*Cosine of the angle of misalignment multiplied by 100.

Source: *Other Homes and Garbage*, Jim Leckie, et al.

TYPES OF SOLAR HOT-WATER SYSTEMS

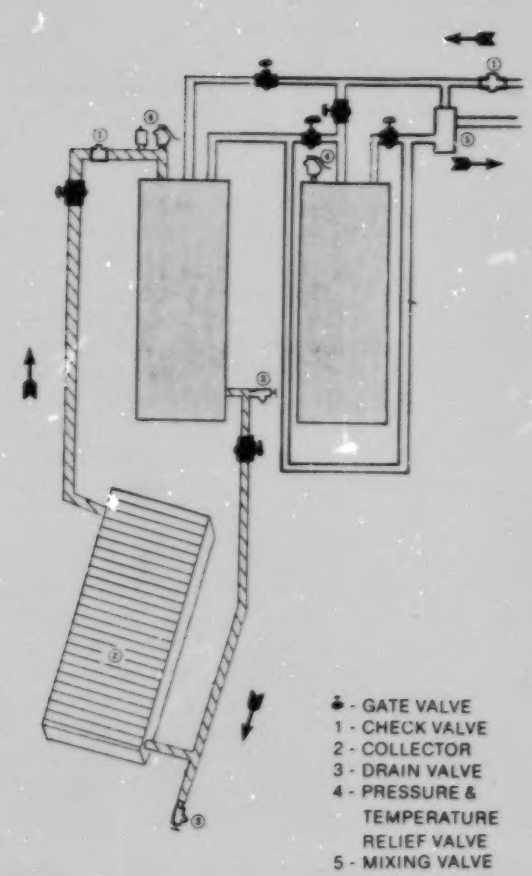
There are two basic types of solar hot-water systems, those that do not circulate and those that do circulate.

Preheaters, which do not circulate, use a storage tank that sits in the sun and performs as its own collector. These preheaters are sometimes referred to as breadboxes, in-line preheaters, or passive-solar preheaters. Because they are usually made from recycled gas or electric water-heater tanks, the materials cost is low and the cost-benefit ratio is usually quite good.

Circulating systems use a collector warmed in the sunshine that becomes the system's heat source. A circulating fluid then transfers that heat to storage. Circulating systems are fairly new — the first system featuring circulation from collector to storage was patented in 1902 by Frank Walker. The two types of circulating systems are thermosiphon and pumped.

CIRCULATING-THERMOSIPHON SYSTEMS

No outside energy is required for the circulation to the fluid in a thermosiphon system. Thermosiphoning is the action of a fluid rising as a result of being hot, therefore less dense, and in this case, being replaced by suction with cooler inlet fluid. In order to prevent reverse thermosiphoning at night and on cloudy days, the bottom of the tank should be at least 2 feet above the top of the collector.



Thermosiphoning is a natural passive circulation, which begins when hot water in the collector begins rising, much like hot air rises from a chimney. Cooler water from the bottom of the tank replaces it as the hot water thermosiphons upward to the top of the tank.

Circulation begins only when there is enough radiation to harvest heat and the flow rate is automatically proportional to the strength of the insolation. Therefore, there is no need for a differential thermostat in those systems.

Open-loop thermosiphoning is most popular in non-freezing climates. In order to drain the collectors without draining the tank, a valve must be provided on the collector supply line to keep the tank full. A collector drain valve will also be necessary. An electric solenoid valve is available that will achieve positive action draindown; that is, the drain is held closed electrically and is opened to the drain position when the power goes out. The valve only draws about two watts, but this thermosiphon system is no longer passive. Suppliers of such valves are listed in Appendix C.

It's also possible to manually drain the system by using gate valves or ball valves.

Thermosiphoning systems that use antifreeze heat transfer fluid do not require draindown provisions and are suitable for use in colder climates.

Because the pressure difference created by the density difference in hot and warm water is small, all effort should be made to reduce friction in the piping. Elbows should be minimized. Manifold piping patterns with headers running level and feeders running plumb are the recommended design. Horizontal piping runs will not thermosiphon.

CLOSED-LOOP SYSTEMS

Closed-loop systems use a heat-transfer fluid, which does not interconnect with the potable water supply. The transfer fluid may be glycol, glycerine, silicone or hydrocarbon fluid, which can stay in the collector during freezing periods without freezing and causing damage. It may also be distilled water, which drains back into a holding tank inside the house when the outside ambient temperature approaches freezing. An air collector system might be considered closed-loop because the air remains separated from the potable water. Closed-loop systems all employ a heat exchanger of some type.

OPEN-LOOP SYSTEMS

Open-loop systems circulate potable water as the heat-transfer fluid. The water used in the household is circulated directly through the collector. Freeze protection is achieved by recirculating, draindown or EPDM collectors (See Freezeproofing).

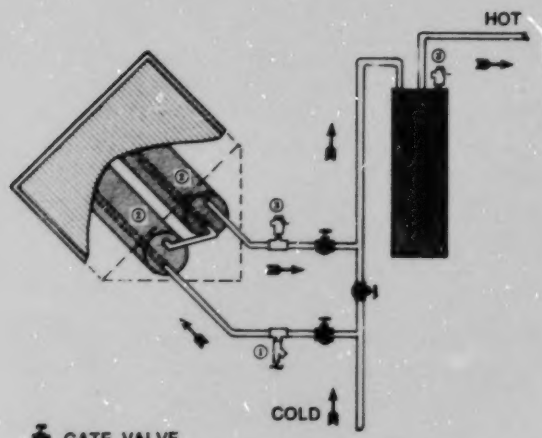
ACTIVE OR PUMPED SYSTEMS

Active or pumped systems use a circulation pump to transfer the fluid from the collector to a heat exchanger or directly to the storage tank, where it gives up the heat it harvested at the collector. Pumped systems allow positioning of the collector and the storage tank where it is most convenient. Their relative positions are important only in sizing the pump. The higher the collectors in relation to the pump, the larger the pump will have to be.

There are two basic types of circulating systems in terms of the circulation loop configuration — closed loop and open loop.

PREHEATERS

Preheating your hot water in a noncirculating preheater is the simplest of all solar heating options. Because it is simple and reliable, it can be the most cost-effective among the alternatives. The approaches vary in detail but the idea behind these approaches is the same. A holding tank or tanks, which sit in the sunshine, are plumbed to the cold water supply by inserting a "T" into the yard line. The preheated water then goes from the preheater to the conventional (existing) water heater in your home. That replaces your 'cold in' line with a 'warm in' line. With no moving parts or outside energy bill, the sun does its work and the preheated water goes into your conventional tank at 80° to 130° rather than the



- GATE VALVE
① - DRAIN VALVE
② - RECYCLED WATER HEATER TANKS
③ - PRESSURE & TEMPERATURE RELIEF VALVE

typical inlet range of 45° to 85°.

These passive in-line preheaters are commonly known as breadbox water heaters because they resemble a breadbox shape after the frame is built around the tank. The principle of a breadbox water heater is simple. An optimal design will use two tanks (or even three) plumbed in series so that the water drawn off the second tank as you use hot water is replaced by warm water from the first tank. Because the cold replacement water enters the first preheater and not the second preheater, the water going into the conventional tank remains warm as hot water is being used. This principle is explained in more detail under the tank description section.

The preheater is made more efficient with reflective surfaces inside the box, and, of course, full insulation around the box perimeter and piping. Underground pipes need to be insulated with a jacketed urethane insulation. Unjacketed pipe insulation such as Armaflex or Thermacell will not hold up under moist underground conditions.

A hinged top to the breadbox with foil-backed insulation facing the inside will act as a nighttime insulation, to minimize heat loss.

A breadbox water heater can be built for $200 or less, depending on how many new materials you purchase and how much used material you can recycle into the project. That is by far the cheapest way to get a solar water heating system on line.

The breadbox system does have its limitations:

(1) It is not very effective in the winter and therefore some designs are targeted at providing service during the eight frost-free months of Arkansas weather;

(2) During the spring and autumn, when air temperature fluctuates above and below water inlet temperature, the efficiency of the system is directly proportional to how well you time the opening and closing of the insulating top. It is unlikely that you will perfectly time when to open and close or that you will be around to do it every time it should be done. Therefore, this manual control method will be less efficient than automatic systems. Despite this limitation, a movable insulated cover will improve the breadbox's overall efficiency;

(3) Because the breadbox is yard mounted, it can be much more difficult to find a place that is not shaded.

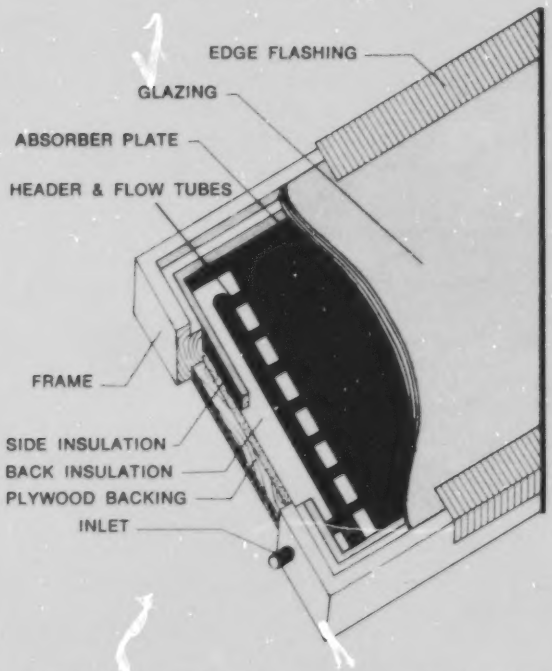
Ordinary window glass may be used as the cover-plate of your breadbox with an efficiency about 15 percent less than the efficiency of a new solar cover plate. Window glass will be subject to breakage from vandalism, hail and tree branches, while tempered glass and acrylics are not subject to breakage. Acrylics should be specified as being ultra-violet resistant if they are expected to remain transparent to light for several years. Kalwall manufactures a coating that can be painted on acrylics to prevent UV degradation. See Appendix C for the Kalwall address.

The average electric water heater consumes 400 kilowatt-hours (kwh) per month. That's $20 per month at five cents per kwh. If the preheat tank raises the temperature from 60° F to 90° F and you're heating to 120° F, that is a $10 monthly savings. With that economic point in mind, it appears to be a feasible consideration in new construction as well as in a retrofit. A passive preheater can be placed in conditioned space and can be used year round. A preheater

system can be retrofitted to an attached greenhouse for very little extra money and will produce a major return on the investment. Tucked up underneath the greenhouse glazing or otherwise positioned inside the heated space, it will not freeze.

FLAT-PLATE COLLECTORS

Because flat-plate collectors are relatively inexpensive and achieve the temperatures required for hot water quite easily, they are the usual choice among the collector types for hot-water systems. Flat-plate collector systems are circulation systems that use the flat plate as the system's heater or furnace.



Flat-plate collectors are easy-to-understand, easy-to-build devices. They consist of an absorber plate, which captures the solar energy, and an insulated box around it, which maximizes the thermal performance.

The sheet and tubes must have an intimate bond, such as continuous solder seam or special thermal epoxy, if a home-built unit is to be efficient. A factory-built absorber plate (See Appendix B) designed into a home-built collector box is as cheap or cheaper than the tube, sheet and solder or glue parts, and probably more efficient. If the absorber is not painted, it should be etched with muratic acid or vinegar before painting. A high-temperature paint is a necessity; stagnation temperatures can reach 350° F.

The collector box can be made of redwood and plywood, galvanized metal, aluminum or whatever durable materials can be economically used.

Just like a storm window, a second cover plate will reduce heat loss; it is recommended north of the Arkansas River valley.

Lots of care should be taken in fabricating the collector frame to assure that it is tightly fitted. Cracks can be devastating to collector efficiency. Conductive heat losses are characteristics of your building materials, but convective losses can be minimized by careful sealing. Latex caulk will work on the back and sides of a wood frame, but silicone rubber caulking is much better. Silicone is expensive, but because your collector will go from 350° F at stagnation to 0° F or less in winter, you will want a good resilient sealer that doesn't lose its flexibility. Silicone should be used to seal the cover to the frame.

Ordinary polystyrene (Styrofoam) and fiberglass insulations are not recommended for use in solar collectors. Polystyrene begins melting at 168° F. As it melts, it produces gas in the process called outgassing. One or two things will result:

(1) The outgassing products will fog the cover plate and render the collector ineffective: and/or
(2) Some of these gases can poison your system.

Fiberglass insulation also outgasses. A petroleum product is added during the manufacturing f fiberglass that outgasses at high temperatures. Owens-Corning Fiberglas, Inc. has introduced two insulations designed for high-temperature use in solar systems. The SI-100 lacks binder completely and is not as fluffy as other fiberglass. It can withstand temperatures up to 1000° F, however. Polyisocyanurate or polyurethane (Thermax, available at most lumber yards) may also be used as collector insulation.

Absorber plates are the heart of the solar collector. Absorber plates may be constructed

from copper, aluminum or steel. They may be purchased ready-made or they may be built by bonding tubing to a sheet of metal. There are several very good absorber plates on the market at a cost that is competitive with the materials-only cost, if you use sheet metal tubing and solder to thermal epoxy. Unless your objective is to teach soldering, or unless you use recycled materials, a home-made absorber is probably not a time-efficient or cost-efficient option. Absorbers are laid out in manifold and serpentine patterns. The most important factor in comparing absorber patterns is the amount of wet area. The larger the wet area, the better the heat transfer; for example, an absorber with transfer tubes on three-inch centers will pick up more Btu's than one with tubes on a four-inch center. There is a point of diminishing return on spacing manifold runs. Most designs have been compromised between efficiency and economy, so that you will have to refer to test results to figure the best deal. A majority of manufactured designs are spaced between two inches and four inches on center.

The surface of the absorber should be either painted with **high-temperature flat-black paint** or with **selective surface.** The optimal absorber has a very high absorbtivity. One that absorbs 90 percent of the energy transmitted through the cover is not uncommon. Selective surfaces, usually a chromate compound, hold their advantage in that they have a much lower **emissivity** than the flat-black paints, because they emit less energy back to the air surrounding the plate. While a selective surface might have an emissivity of .25, a typical emissivity of black paint is .90. The result is that an absorber with a selective surface is about 10 percent more efficient across the range of most normal operating temperatures. The cost of a selective-surface coating runs about $1.50 per square foot of collector area. Applying a selective surface is a plating process, which is only possible with industrial equipment. Several absorber companies offer pre-surfaced selective surface absorbers.

At working conditions, where there is little difference between ambient temperature (surrounding air) and collector temperature, you might expect the following efficiencies:

Steel Absorber	50 percent
Aluminium	55 percent
Aluminium Plate, Copper Tubes	60 percent
All Copper	75 percent

These figures would represent top efficiency, which is experienced during summertime conditions. They will vary substantially with varying collector designs.

The next component to be considered is the **cover** or **glazing.** The glazing is that marvelous part that creates the "greenhouse effect" and allows the whole process to work efficiently. Sunlight, composed of short wavelengths, passes through the cover and strikes the absorber. The sunlight becomes a longer wave — too long to pass back through the glass. It is the same working principle that heats up your locked car to 130° on a sunny day.

A single-glazed collector will do well in Arkansas, although the added expense of a double-glazed one might be justified in the northern part of the state.

Typical glazing materials for collectors include fiberglass, reinforced acrylic, polycarbonate, tedlar, teflon and tempered low-iron glass. Tedlar and mylar are usually reserved for the inner layer of double-glazed units.

Ordinary window glass is not recommended for most collectors because:

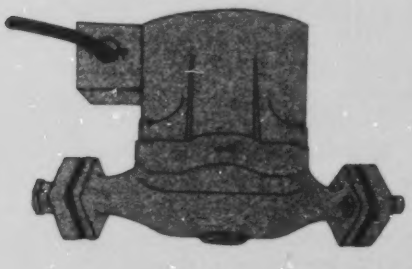
(1) It is potentially vulnerable to breakage by hail, vandals, limbs, etc.

(2) Its high lead content severely reduces the transmissivity qualities.

A final collector component is a temperatures sensor or thermister. It is attached to the surface of the absorber in systems that are controlled with a differential thermostat. These sensors are small transducers that relay the collector temperature to the differential thermostat. The differential thermostat then sets the pump and valves into the appropriate off-on positions. Thermister placement is critical to proper system operation. It should be positioned so that it's never shaded by the collector frame.

CIRCULATING SUBSYSTEMS

PUMPS



There are several off-the-shelf solar pumps — Grundfos, Little Giant, Taco, and Richdel, among others. A one-twentieth horsepower pump will accommodate up to four collectors and as much as a 12-foot head. That's sufficient for most systems, although the actual flow rate under a certain circumstance is also dependent upon piping size, length, and number of turns and the static pressure caused by valves and instruments in the system. Most solar water-heating system pumps are centrifugal pumps. Centrifugal pumps will build less pressure under clogging conditions than displacement pumps, so they are less dangerous if the collector or loop become blocked.

The recommended flow rate for water-heating systems is .02 to .25 gallons per minute per square foot of collector area. A 50-square foot collector area would have an optimal flow rate of 1 to 1.25 gallons per minute; the 75-square-foot collector has a rate of 1.5 to 1.87 gallons per minute, etc.

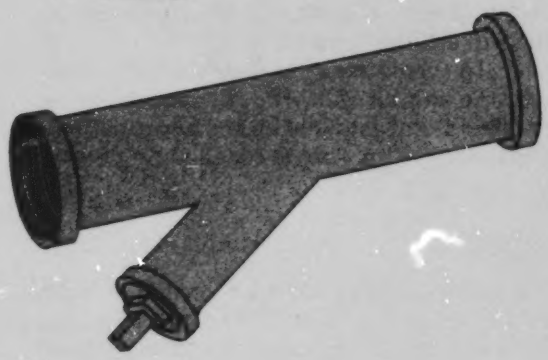
A one-twentieth horsepower pump uses about 65 watts or about .8 amps (110 volts AC) when running. A pump that runs continuously from 10 a.m. to 2 p.m. would use under .5 kwh per day or about three cents worth of electricity per day. Electric draindown valves and differential thermostats also use small amounts of power, usually under 10 watts. Energy consumption by these components is called parasitic energy loss. A well-designed system might incur parasitic loss of 3 to 5 percent of the total amount of energy collected. A poorly-designed or poorly-functioning system can incur up to a 20 percent parasitic energy loss.

LINE STRAINER

A strainer should be inserted into the loop on the suction or inlet side of the pump. It will catch sediment from the tank as well as large scalings that might come from the water supply. In order to protect the pump as much as possible, the strainer should be cleaned regularly. This is especially important if:

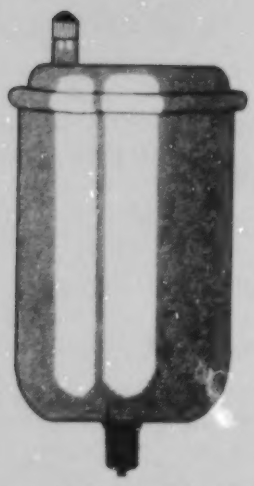
(1) the system is a draindown system and scaling from mineral deposits and air interacting is likely, or

(2) the collector supply loop is a converted drain opening and is therefore at the very bottom of the tank, where all of the scale build-up is located.



AUTOMATIC AIR VENTS — VACUUM BREAKERS

All systems with a pressurized-collector loop should have an air vent at the top of the system. The top of the system will be either the collector outlet manifold, which is the hot out, or that same line as it enters the tank. The air vent will allow air trapped in the lines out of the system and thereby keep the flow up to design flow rate. The air vent also allows water to displace air in the lines while filling the collector loop, and it allows air to displace the water when the system drains down. Systems that drain frequently might also require an air eliminator. The air eliminator is a part with baffles across the water flow, which aerates the water and sends air bubbles to the air vent that sits on top of it. Proper slopes on the piping runs will

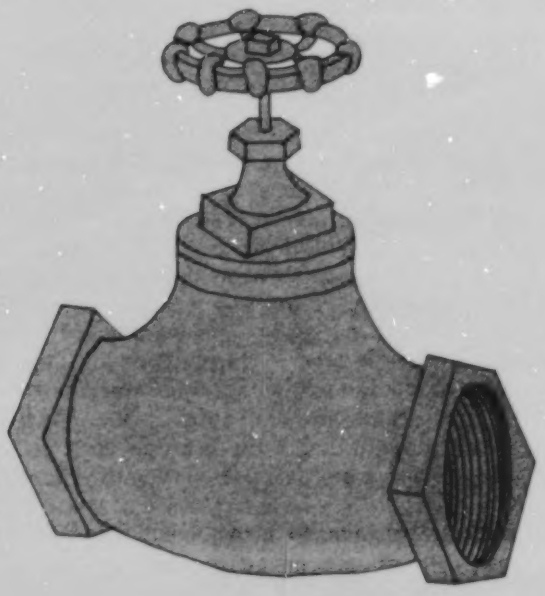


minimize air pockets (See Installation Section). Large collector arrays might require several air vents to facilitate good flow.

Most air vents use a float to block water while allowing the air out. The air vent must be installed plumb (straight up and down, perfectly vertical) for the float to function properly.

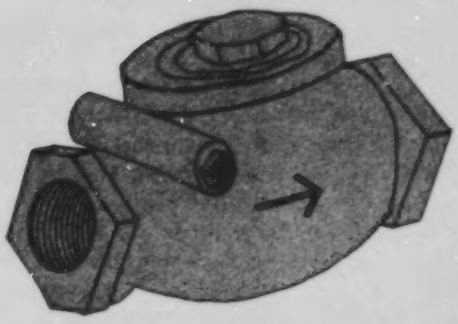
ISOLATION VALVES AND UNIONS

Isolation valves should be located on each side of the pump, the tank and the collectors. They will allow maintenance and/or replacement without draining the entire system. They will also allow continuous operation during repairs. Ball valves, globe valves and gate valves are accceptable for isolation valve uses.



Consistent with good plumbing practice, unions should be placed where components and piping runs can be disassembled with a minimum of pipe cutting. Obvious places for unions are between the isolation valve and storage tank on the cold inlet line, between collectors and manifolds or expansion joints, on each side of welded or threaded pipe pumps, after the isolation valve on the collector supply from the tank, and just before the strainer.

CHECK VALVES



Water and other heat-transfer fluids tend to convect their heat from warmer to cooler areas. This action, thermosiphoning, is desirable when heat is traveling from the collector to the tank naturally; but the flow reverses when storage is warmer than the collector. Reverse thermosiphoning of this type can be prevented by installing a check valve in the collector loop.

A swing-type check valve allows fluid to travel in one direction only. A check valve should be located in the return side of the collector loop, especially if the tank is a few feet beneath the collector. Check valves must be installed horizontally to work well.

PIPING

Copper tubing, type L or M rigid, should be used in the collector loop. Three-quarter-inch

piping is most common, but half-inch may be used for economy if the system is small and the head is not very large. All pipes should be insulated. Expansion connections of the collector manifold and silver solder (see Overheating Protection) will minimize thermal damage to piping.

Polyvinyl chloride pipe is not suitable for collector use. Polybutylene and chlorinated polyvinyl chloride pipes may be used as a less expensive substitute to copper.

A fill point is a necessity in every system. The fill point should be located where it is convenient to set up a temporary pump and bucket for charging the system in closed-loop systems.

HEAT TRANSFER FLUID

Air, water and freeze-proof liquids are the heat-transfer fluids used in these systems. Air systems using the air-to-water heat exchanger use the cheapest and least troublesome fluid — air. Water is a cheap heat-exchange fluid, too, and can be used in open-loop systems without a heat exchanger.

Propylene glycol, ethylene glycol, oil-based liquids or silicone-based liquids are usually used in closed-loop systems. The specific heat of these fluids is lower than water, so they will pick up less energy (probably only 85 percent or so) than an equal amount of water would under the same conditions. However, since they will not freeze like water, they are often used to avoid having to drain the collector during freezing weather. Many of those fluids are thinner than water and might, therefore, leak at a connection or pump that is watertight.

STORAGE TANKS

The storage system may be one or two tanks. The tank that connects to the solar collector loop should be about twice the size of your existing water tank. Solar storage tanks are well insulated to retain maximum heat for long periods. Sizing your storage and deciding between a one-tank and a two-tank system are dependent upon your "draw patterns". Draw pattern refers to your water usage pattern, considered and analyzed within a time frame.

The offsetting factors in choosing between one and two tanks are extra usable heat gained in storage by the second tank and the increased system heat loss by the second tank.

Let's first consider a fast-draw no-recovery example. The example will compare a one tank, 120-gallon system to a two-tank system with an 80-gallon tank and a 40-gallon tank. The tanks will all start out with 120° F average water temperature. The inlet temperature is 70° F.

Draw 10 gallons from the 120-gallon tank system (take a warm shower) and the resulting temperature is [(110 gallons × 120°) + (10 gallons × 70°) ÷ 120 gallons] or 116° F. The 40-gallon tank is replaced with 120° water so it remains 120° , but the 80-gallon tank temperature drops to [(70 gallons × 120°) + (10 gallons × 70° ÷ 80] or 144° F.

Drawing 10 more gallons (another warm shower), the 120-gallon tank temperature drops to [(110 × 116) + (10 × 70) ÷ 120] or 112° F. As the no-recovery profile continues, the two tank system performs increasingly better than the one-tank system.

The draw pattern at the other end of the spectrum from a "no recovery between draws" pattern is the "no load" profile. In a tank that has achieved its maximum storage temperature and has no load (no demand), all of the delivered energy is a "heat loss". It may be a tank loss via temperature and pressure valve, collector stagnation heat loss, purge coil or a combination of those, but all gains are also losses if the storage is fully charged.

Neither the "no recovery" nor the "no load" draw pattern is experienced in real working systems. Examination of those patterns reveals the consequences of undersizing or over sizing storage. An undersized system will more closely resemble the no-recovery pattern when it is being drawn down. An oversized system will have less overall load per unit storage.

The storage tank heat losses can be calculated by multiplying the tank's surface area times the temperature difference between the storage water and the storage room air and then dividing the resulting product by the R-value of the tank's insulation ($\frac{A \Delta t}{R}$). For a cylindrical tank h high and d in diameter, the heat loss

is [3.14d (h + 2d/4)] Δ t ÷ R-value. A 30-gallon tank with 3½ inches of fiberglass with 120° F water in a 70° F room loses 64 Btu/hr. or 1,536 Btu/day (1 feet diameter, 4.33 feet height, no load, no recovery). That means the temperature would drop 6° F per day if there were no load or recovery (no showers, no sunshine). For most systems, except the extremely-oversized or infrequently-used systems, two tanks boost the efficiency by delaying the temperature drop to the backup element's temperature set point.

A two-tank system also heats only a part of your storage with the backup element when storage temperatures drop. Except under long continuous draws, that is more energy efficient than heating one large tank to the set temperature.

RECYCLED TANKS AS SOLAR LOOP TANKS

As previously noted, discarded water tanks can be used creatively in a variety of passive or breadbox designs. They may also be recycled into service as the tank that is in the collector-circulation loop. Natural gas tanks may be recycled as closed-loop tanks and electric water heaters are best suited to open-loop adaptation.

RECYCLING A NATURAL-GAS-FIRED TANK

Natural gas tanks are often abandoned because the valve or pilot light assembly malfunctioned. Lots of water tanks at your local junkyard don't leak a drop under working pressures of 150 pounds per square inch (psi) or lower. Others can be easily spot-welded if they have small leaks. (Glass-lined tanks may not be repaired by welding). Because the solar loop tank often doesn't have a backup element in it, the crippled old gas-fired tank is still good for the solar loop.

First, strip the jacket and the insulation from the tank. Remove the temperature and pressure valve and the fittings from the tank. Plug all openings with galvanized threaded "plugs" except one opening that accommodates a hose for filling and pressure-testing the tank.

The gas-fired tank has a flue stack two inches round through its center. By welding a two-inch female pipe thread (FPT) coupling and adding a two-inch male pipe thread (MPT) to three-quarter-inch female pipe thread bushing on each end, the tank is ready for mounting. Propylene or ethylene glycol can now be circulated from the collector through the vent stack for freeze-proofing protection. The exvent stack becomes a heat exchanger. Commercially-available immersed heat-exchanger tanks are somewhat more efficient and include a warranty against leakage, but at a much higher cost.

The tank may be insulated with fiberglass batts or blanket. Duct tape is recommended for taping the batts together. A good, carefully-taped application is firmly in place without gaps, but does not compress the insulation. Some tanks have a hollow space under the tank bottom where insulation will fit. Others might require an insulated platform to minimize tank losses from the bottom. This also allows room for the coupling, bushing, and ell.

This method of converting the used water heater tank is accomplished with $5 worth of couplings and bushings, $10 or $15 worth of welding and a very small scrap water heater cost. A plumber can locate a tank for you or you might find one at your local junkyard or landfill.

CONVERTING AN ELECTRIC WATER HEATER INTO A SOLAR STORAGE TANK

An electric water heater can be converted into a solar storage tank with common plumbing connections.

First, turn off the power to the circuit breaker that services the water heater. Open the access covers. Use a circuit tester to test for current before handling bare wires. Disconnect the wires leading to the bottom element. The top thermostat goes to the bottom element. Wrap the wires to that connection with electrical tape and push them apart. Set the upper heating element to 120° F. Close the upper

access hole.

Turn off the water supply line to the tank at this point. If there is not an isolation valve at the cold inlet to the tank, add a gate valve or ball valve that will isolate the tank from the supply when desired. Attach a hose to the drain valve at the bottom of the tank and run the hose to a drain. Open the highest hot water faucet in the building, close the supply valve to the tank, then open the tank drain valve. Allow the tank to drain.

COLLECTOR INLET LINE

Some tanks use elements with one-inch threaded pipe connections. After the bottom element has been removed, a one-inch female pipe thread (FPT) port is left. This opening is easily adapted to a three-quarter-inch or half-inch fitting, which adapts to the collector supply or cold inlet line.

The connection to the element might be bolted and flanged to the tank wall. An adaptor from the hardware store is available to adapt that opening to one-inch female pipe thread. Although having to remove the insulation and tank jacket will make the lower element removal a chore, this is the best port for use as the collector supply line.

Another option details the collector supply line teed off the street cold water inlet line. That design is not suitable in thermosiphon systems or heat-exchanger systems.

A third option uses a tee off the tank drain to provide the collector supply loop. This is suitable for open-loop applications. Because the drain valve catches scale particles, a strainer is critical. This type of plumbing will require more frequent flushing and strainer cleaning than the other options.

COLLECTOR RETURN LINE

The port formerly used as a hot-water outlet is converted to the collector return line. A pipe inserted to reach a third off the way down into the tank from that port will moderate stratification, but is not critical.

The automatic air vent should be on that line, either at the tank or the collector, whichever is higher.

All of these conversion methods are completed by teeing the pressure and temperature relief valve to provide the hot-water service line. A long-stemmed pressure and temperature relief valve will be needed to reach into the tank through the tee.

Close the isolation valves to the collectors and fill the tank. Fill the collector loop and vent air vents, pressure and temperature relief valves and plumbing to faucets.

Attach the "cold" or storage sensor to the tank under the insulation near the bottom. Use care to make good contact with the tank and replace the insulation well. Pinches and kinks in the sensor wire can affect the accuracy of the reading, so caution is necessary to prevent wire damage.

Add a 3½-inch fiberglass batt and secure neatly and accurately with duct tape. That method has four times the R-value for under half the cost of most water-heater blanket packages. An insulated platform, framed out of two-by-fours, will reduce heat loss through the bottom of the tank.

Your electric water tank is now ready for service as a solar storage tank.

CONTROL SUBSYSTEM

It's possible to control manually an active system with a pump switch, and by manually switching the system off and on. This might be done at a summer fishing cabin. This reduces system costs by $50 to $100. It's unlikely, however, that you will consistently and accurately predict sunny Arkansas weather and cloudy Arkansas weather as you leave for the shop, office, or classroom, each morning.

It's important to have a control system on solar water-heating systems so the system will:

(1) Harvest maximum energy. The controls continuously sense the best choice between circulating and off, to harvest Btu's only when worthwhile.

(2) Provide automatic (and hopefully fail-safe) freeze protection. A solenoid on the drain is held closed by electricity or a power failure. Recir-

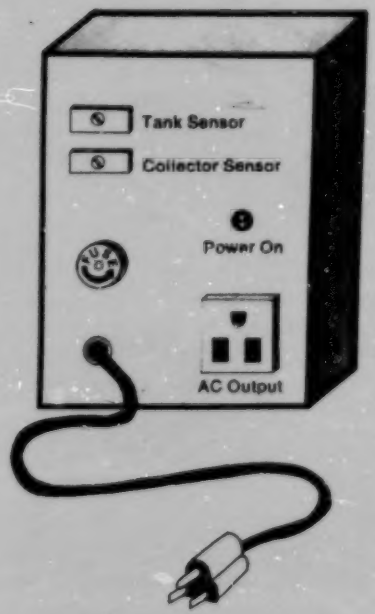
culating controls activate the pump for freeze protection, but these will fail in a power failure.

(3) Provide automatic overheat protection. This is variously accomplished by draining the collector, allowing the collector to "stagnate" when storage capacity is reached, or in large systems, dumping the heat through a purge coil.

DIFFERENTIAL THERMOSTATS

The differential thermostat is the brain of the control system. It controls the pump and any solenoid valves used in draindown loops and purge coils. The basic function is to measure the temperatures of the collector's absorber plate and the tank and determine whether the pump should run or not, based on those measurements.

A differential thermostat differs from a setpoint thermostat in that it works on the basis of the amount of temperature difference between two stations; it does not consider what those temperatures are. In solar water heating systems, the differential thermostat turns the pump on when the collector temperature is a predetermined temperature hotter than the storage tank, perhaps 15° F hotter. The higher temperature may come set at a fixed differential or it may be a model that can be adjusted by the user.



As the pump circulates the transfer fluid, the tank picks up heat. When the tank temperature approaches the collector temperature, the differential thermostat senses the smaller temperature difference and shuts the pump off. The low temperature difference is preset; it might be 1.5° F, 3° F, or 5° F.

The differential thermostat also automatically initiates draindown modes, recirculation modes and overheating remedies, when they are designed into the system.

The sensors that sense the temperature, thermisters, may be either the transducer or the thermopile type. It's important that the thermister have a good surface contact with the collector and tank. Thermisters that activate the draindown function should fit at the collector inlet point and should remain uninsulated.

Control systems are sometimes the cause of a system failure. A system that has temperature stations at the cold inlet and hot inlet of the collector (with in-line or digital thermometers) can reveal control system malfunctions by giving you the actual temperature difference across the collector.

MONITORING SYSTEMS

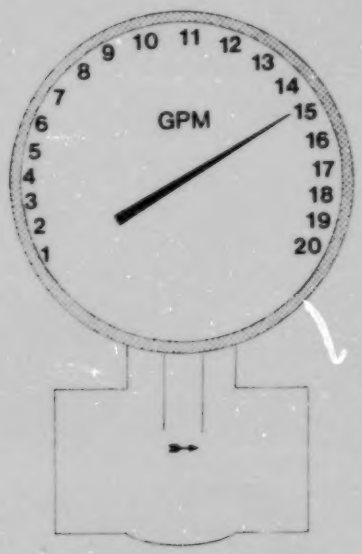
A system may be functional without any measured temperature of flow rate readings, but an inexpensive combination of thermometers and flowmeters can be helpful in system balancing and troubleshooting. System balancing involves adjusting the flow rate and collector in and out temperatures to optimal settings for maximum energy gain.

The proper flow rate through the collector may be obtianed by optimizing the temperature difference (Δ t) in the collector inlet and outlet. This is most inexpensively accomplished by sight reading in-line thermometers (such as Letro's — about $13 each). This is practical only in stand-up attics immediately through the roof penetration, in yard-mounted arrays, or in

otherwise accessible collector arrays. A remote digital thermometer costs about $75 but adds an ambient air sensor capability. The temperature difference, Δ t, between collector inlet and outlet should be 10° F to 20° F when the collector is in full sun. By slightly closing the balancing valve, the flow rate is slowed down and the temperature difference across the collector rises.

FLOWMETERS AND BALANCING VALVES

A flowmeter that reads the instantaneous flow rate is useful in determining if the circulation is within the recommended flow range of .02 to .025 gallons per minute per square foot of collector. The temperature difference between collector inlet and collector outlet will also give you an indication of the proper flow rate, but a direct reading will double check the system's proper operation. The recommended flow rate should allow a 10° F to 20° F rise in fluid temperature across the collector after the system is fully warmed up.



The flow rate can be adjusted by a balancing valve, which can be a ball valve or a gate valve between the pump and the collector. In larger systems these balancing valves are required to equalize flow through each collector.

Although these components might not be necessary in a package system, they compensate for some mismatching in component systems and allow tuning for optimal operation. Flow-balancing components and thermometers will help you diagnose a system malfunction, even though the backup element continues to provide hot water at the thermostat's set temperature.

PERFORMANCE MONITORING SYSTEM

The simplest, cheapest and least-accurate performance monitoring system uses an elapsed-time meter ($10-$20) (See Appendix C), a totalizing water meter ($50), and a pocket dial thermometer ($10). The hot and cold tap-water temperatures are measured during times of typical usage and $T_{hot} - T_{cold}$ is averaged. The product of water usage times the temperature difference times the heat capacity of water (8.34 Btu/gal/° F) is the total amount of heat delivered. An example month might be:

2400 gallons × (130° — 70°) × 8.34 Btu/gallon /° F = 1,200,000 Btu's.

The elapsed-time meter is wired into the electric backup element. The monthly backup energy used is determined in kwh, by multiplying the hours it ran that month by its rating.

Example:

48 hours × 4.5 kw (4,500 watt backup element) = 180 kwh. Because 1 watt = 3.413 Btu; 180 kw × 3,413 Btu/kwh = 614,520 Btu's.

Another elapsed-time meter may measure energy used by the pump. Disregarding parasitic losses, the monthly solar fraction in this example is (1,2000,000 — 614,520) ÷ 1,200,000 = .49 or 49 percent.

The result would be more accurate with in-line thermometers at the tank on the inlet and outlet lines, but at additional cost.

Because cold water replaces the hot water in storage, the hot-water temperature is warmer at the beginning of a draw than it is near the end. The performance test result is much more accurate if the hot out is measured before and after a draw, and those two readings are

averaged.

SIZING THE COLLECTOR ARRAY

In sizing the heating systems of various sorts, the conventional method is to select design conditions — coldest winter temperature and the load or demand — and size the system to meet the total demand. This is not the case in sizing a solar system for space heating or water heating.

The fraction of total energy supplied by the sun follows the law of diminishing returns in relation to increasing collector size. A collector array of 48 square feet might provide 50 percent of the water-heating needs of a given home; 72 square feet might provide 70 percent of the water-heating needs of a given home; 72 square feet might provide 70 percent of that need; 96 square feet would provide perhaps 79 percent. Doubling the collector size adds as much as 50 percent to the cost of the system, but only 29 percent to its percent of contribution.

Sizing the collector system is dependent on demand — the total demand and when the use period occurs. The following rules are based on payback considerations:

(1) The system should be capable of providing 100 percent of the load in the summer.

(2) It should provide no more than 40 to 50 percent contribution in the coldest winter months.

(3) The annual contribution should be 50 to 75 percent.

SYSTEM SIZING BY RULES OF THUMB

If you want a system that will make a substantial contribution to your water-heating load at a fairly good rate of return, but do not wish to calculate the details, you may use the following rules:

(1) The storage tank or tanks should hold about 20 gallons of water per person; plan more for small families, and perhaps less for very large families. Remember that in two-tank systems, the optimal sizing is a solar-loop tank twice the size of the backup tank.

(2) The collector area should be 0.4 to 1 square foot per gallon of storage. A high-efficiency, double-glazed collector would be suitable for the low-end of the range and a homemade, single-glazed collector for the top end.

More exact sizing can be accomplished by determining load and calculating the proposed system's contribution.

CALCULATING THE WATER-HEATING LOAD

In order to size the system, you must first figure what your load or demand will be. The demand is determined by calculating the amount of heat per gallon times the number of gallons required. A sample calculation and a blank worksheet are provided in Appendix A for detailed calculation. Column E can be adjusted from 10 to 25 gallons per person per day depending on your ability and willingness to conserve hot water. The final answer is in million Btu's per month.

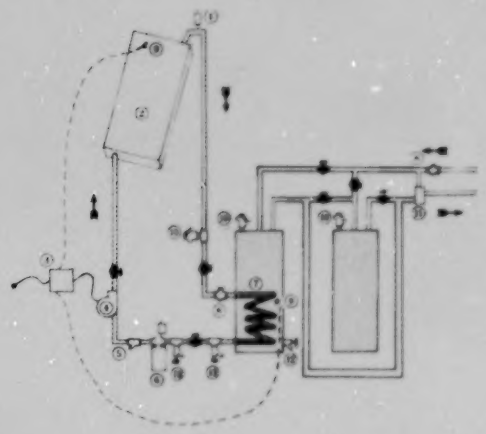
Worksheets will give a percentage of solar contribution and payback for various-sized systems based on your own demand assumption.

FREEZE-PROOFING

Because the collector is located outside and even the southernmost parts of Arkansas are subject to freezing temperatures, some method of protecting the collectors from freeze damage must be provided. There are a number of options available for freeze-proofing the system. The choice depends upon whether the system is new or retrofitted, and other installation considerations.

CLOSED-LOOP SYSTEMS

Systems that keep the heat-transfer fluid separate from the potable water that is heated are called closed-loop systems, because there is no interconnection between the collector loop and the potable-water supply. Closed-loop systems may employ distilled water as the transfer fluid. Distilled water holds a thermal advantage over glycol (antifreeze) solutions, because its specific heat or ability to hold heat is 14 percent better than glycols. A closed loop using distilled water usually has a draindown or drainback function, which empties the water in the collector into a freeze-proofed area. Distilled water is used to prevent mineral oxidation and scaling that may occur as a result of air and minerals interacting.



♣ - GATE VALVE
1 - AIR VENT
2 - COLLECTOR
3 - DIFFERENTIAL THERMOSTAT
4 - PUMP
5 - STRAINER
6 - EXPANSION TANK
7 - HEAT EXCHANGER
8 - CHECK VALVE
9 - TEMPERATURE SENSOR
10 - PRESSURE & TEMPERATURE RELIEF VALVE
11 - MIXING VALVE
12 - DRAIN VALVE

Most closed-loop systems use ethylene or propylene glycol or an oil-based heat-transfer fluid. Because these fluids have low freezing points, they can remain in the collector during freezing periods without causing damage to the collector.

The heat exchanger that transfers the heat from the transfer fluid to the water may be one of several types. An immersed heat exchanger is built into some tanks. The collector loop enters the tank at a port, usually near the bottom of the tank, and passes through a coil immersed in the tank. The heat-exchanger coil may be single or double-walled. The immersed heat exchanger is an efficient heat-transfer method. Wrap-around heat exchangers are also available to retrofit conventional storage tanks for closed-loop systems use. The insulation is stripped off the tank and the heat exchanger is wrapped around the tank and secured. A value of R-19 is not excessive in reinsulating the tank, although R-11 might be adequate for systems that have heavy use patterns in midday.

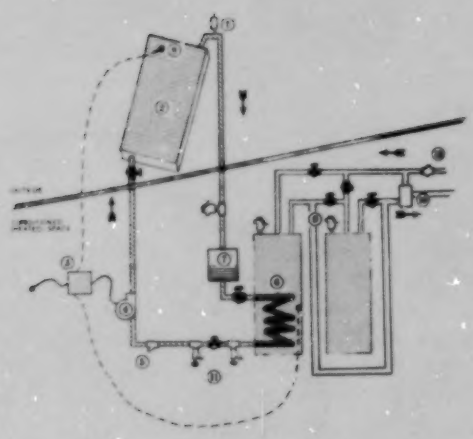
A counter-flow heat exchanger can also be used in closed-loop systems. As the name implies, the exchanger accommodates heat-transfer fluid flow in one direction and potable water flow in the other direction. This creates a quite efficient heat exchanger if the flow rates are properly set, but at the expense of additional parasitic loss. A second pump typically is required to circulate the potable water through the heat-exchange loop. Counter-flow heat-exchanger systems are controlled to require both pumps to start and stop together.

DRAINBACK SYSTEMS

A drainback system is a type of closed-loop system that uses water as the heat-transfer fluid. Distilled water is typically used because it lacks minerals that can cause scale and corrosion.

The system is controlled with a differential thermostat, as the other closed-loop systems are. The pump is activated by a signal from the differential thermostat when sensors indicate the collectors are warmer than the storage tank.

The basic difference in drainback systems and other closed-loop systems is the method and extent of charging the system. The loop is charged by filling the system until the drain reservoir is nearly, but not completely, full. When the pump starts circulating, the drain reservoir level drops to about half full. The system is not under any pressure. As the pump quits pumping, the water drains out of the collectors back into the drain reservoir.



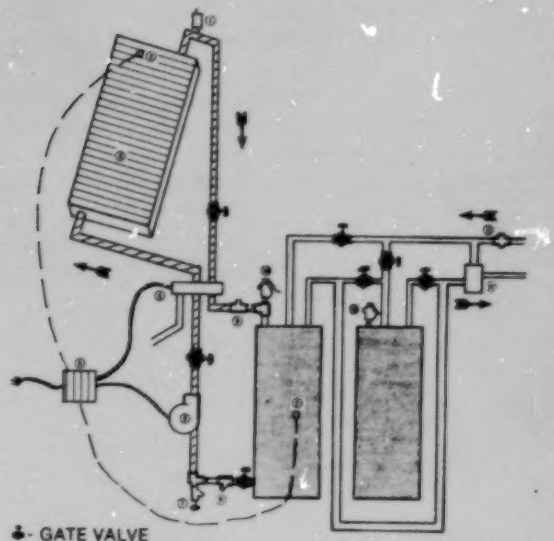
- GATE VALVE
1 - AIR VENT
2 - COLLECTOR
3 - DIFFERENTIAL THERMOSTAT
4 - PUMP
5 - STRAINER
6 - HEAT EXCHANGER
7 - DRAINBACK RESERVOIR
8 - TEMPERATURE SENSOR
9 - TEMPERATURE & PRESSURE RELIEF VALVE
10 - MIXING VALVE
11 - DRAIN VALVE
12 - CHECK VALVE

Because the reservoir and pump are in a conditioned (heated) space, there's no danger of freeze damage to the collectors or piping. Garages, utility rooms or workshop spaces that might freeze are unacceptable locations for the pump and drain reservoir.

Drainback systems pumps should be about twice as large as other circulating systems, usually one-twelfth horsepower.

DRAINDOWN SYSTEMS

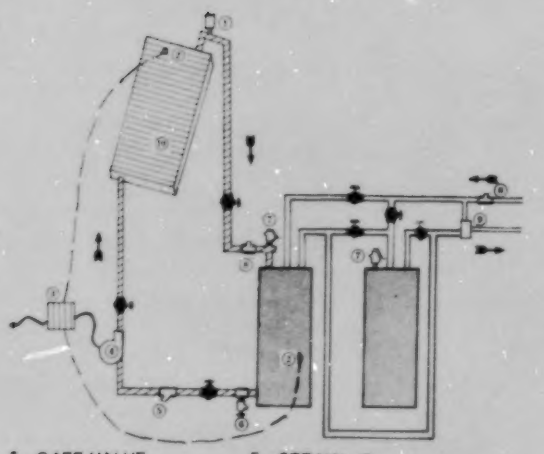
Draining the collector of its water during freezing periods is one way to prevent ruptures caused by the expansion of water as it turns to ice. The drain may empty into a gutter, the sewer or a storm drain. That is not too serious a waste because a typical collector array will hold only a couple of gallons of water when full. Draindown may be accomplished by a solenoid valve, which opens when near-freezing temperatures are sensed by the collector's sensor. The valve should be normally open and should be held closed electrically during non-draindown periods to guarantee draindown in the event of a power failure. This means there is a constant parasitic loss when the system is not drained, but it is a very small amount (one or two watts continuous power use). An additional solenoid valve is needed to cut off the water supply. A valve that covers both of these functions is marketed by Sunspool (see Appendix B).



- GATE VALVE
1 - AUTOMATIC AIR VENT
2 - TEMPERATURE SENSOR
3 - COLLECTOR
4 - SOLENOID DRAINDOWN VALVE
5 - DIFFERENTIAL THERMOSTAT
6 - PUMP
7 - DRAIN VALVE
8 - STRAINER
9 - CHECK VALVE
10 - TEMPERATURE & PRESSURE RELIEF VALVE
11 - MIXING VALVE

RECIRCULATING SYSTEMS

Circulating the water through the collectors during freezing weather will prevent freeze damage. This is the simplest of the approaches because it requires no additional parts to implement freeze protection beyond the collector temperature sensor, the pump and a differential thermostat that is pre-programmed to activate the pump at freezing and near-freezing ambient temperatures. Because of its simplicity, it has the cheapest initial cost for protecting your system. Pumping costs accrued during recirculation periods are parasitic losses and may become substantial during extended sub-freezing weather. Recirculating systems, consequently, will be a better selection for the central and south sections of the state than the



- GATE VALVE
1 - AUTOMATIC AIR VENT
2 - TEMPERATURE SENSOR
3 - DIFFERENTIAL THERMOSTAT
4 - PUMP
5 - STRAINER
6 - DRAIN VALVE
7 - PRESSURE & TEMPERATURE RELIEF VALVE
8 - CHECK VALVE
9 - MIXING VALVE
10 - COLLECTOR

north section. A one-twentieth horsepower pump will use about 50 kwh/month if it runs continuously, as it would have in January, 1977, in Fayetteville. Most typical winter situations would consume substantially less, but the system parasitic losses should be considered in system selection.

Substantial heat losses occur as the water recirculates, which also lowers system efficiency.

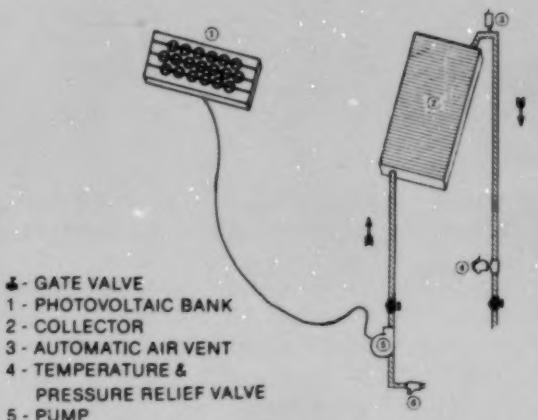
PHOTOVOLTAIC POWERED SYSTEMS

Another type of circulating system is powered directly by photovoltaic (fō´tō vōl ta´ic) or solar electric cells. Freeze protection is achieved by circulating glycol or silicon oil in a closed loop or by using non-metal collectors. The photovoltaic (PV) module or array is usually wired directly to the pump so that the pump circulates the heat transfer fluid automatically when there is direct sun. Circulation stops when clouds appear, and as the sun goes down. The flowrate is proportional to the sun's intensity; it's faster during clear periods and slower in hazy, foggy, and smoggy conditions. Because of the direct hook up from the pump to the PVs, there's no need for a differential thermostat or any other electronic logic.

A typical pump in a domestic solar hot water system is one-twentieth horsepower. One horsepower is 746 watts, so one-twentieth horsepower is about 37 watts. Because the pump is rated at 'power out' and is about 50 percent efficient, a one-twentieth horsepower pump will draw about 80 watts fully loaded. Smaller systems and those with a low head may function well with about half that pumping capacity.

PV-powered hot-water systems are very efficient collection systems, although the initial cost is somewhat higher than most other systems.

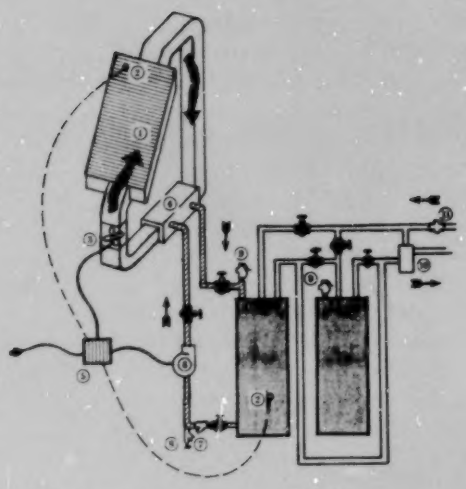
12 VDC pumps are available from Hartell Division, 70 Industrial Drive, Northampton Industrial Park, Ivyland, PA 18974.



- GATE VALVE
1 - PHOTOVOLTAIC BANK
2 - COLLECTOR
3 - AUTOMATIC AIR VENT
4 - TEMPERATURE & PRESSURE RELIEF VALVE
5 - PUMP
6 - STRAINER

AIR COLLECTOR SYSTEMS

Hot water can be provided through the use of air collectors and an air-to-water exchanger. The collector loop is now ductwork rather than piping. A duct coil, which contains circulating water, is heated by the air being blown through the collector-return duct. The control method is similar to liquid-collector systems. The fan and pump are activated together at perhaps 10° F or 15° F temperature difference (Δ t) between the collector and storage sensors. The system might shut off or stagnate when the storage temperature is 180° F.



4 - GATE VALVE
1 - COLLECTOR
2 - TEMPERATURE SENSOR
3 - FAN
4 - DUCT-COIL HEAT EXCHANGER
5 - DIFFERENTIAL THERMOSTAT
6 - PUMP
7 - STRAINER
8 - DRAIN VALVE
9 - TEMPERATURE & PRESSURE RELIEF VALVE
10 - MIXING VALVE
11 - CHECK VALVE

Ducts should be sized for an air velocity of 700-1,000 feet per second. Total pressure in air-collector systems is about twice the pressure of conventional systems, so blowers should be oversized accordingly. The total pressure drop in the system will be about one-half inch of water.

Air collector systems have some distinct advantages:

(1) No corrosion problems or scaling

(2) No liquid leak problems

(3) No boil-overs

(4) Free heat-transfer fluid

Some disadvantages of air systems are:

(1) Ductwork is likely to leak more energy than piping, due to its larger surface area and its less bothersome leak

(2) The pump and fan increase circulation costs

A minimum value of R-4 duct insulation carefully installed is recommended for all ducts.

EPDM SYSTEMS

Ethylene propylene diene monomer is a resilient rubber that will not crack or break between —60° F and 375° F. The very low co-efficient of expansion makes it well suited for use in a system that circulates water in freezing climates. Using EPDM as an absorber is only one of many uses of this versatile material. It is also suitable for use as transfer tubing, in radiant heater panels, for ceilings, walls and floors, or as a heat exchanger. The control system for an EPDM collector system need not have a draindown or recirculate function.

EPDM systems look promising for pool heating and snow melting, as well as for those previously mentioned.

Disadvantages include the slight oversizing that is necessary compared to metal collectors. A potential disadvantage is the lack of long-term test data. Additionally, the designer is limited by headers that are subject to freezing on one commercially-available system.

Solaroll and Sunroll (See Appendix C) are two manufacturers of EPDM solar systems. Solaroll provides its customers with do-it-yourself workshops, decreasing the homeowner-installer's initial cost.

INTERIOR INSTALLATIONS

By locating the collector area in a conditioned space, two major advantages are realized:

(1) The annual efficiency is boosted because the collectors work much more efficiently at 65° F than at winter temperatures.

(2) Freeze-proofing is accomplished. The collectors should maintain the same orientation and tilt as any other array.

The most logical inside space for collectors would be an attached solar greenhouse or a conditioned attic space. They might also be placed in a south-facing winterized porch, or in any south room with extra space.

PIPE INSULATION

All pipes in a collector loop and hot-water supply lines should be insulated to a value of R-4. Valves such as check valves and air vents should also be totally insulated. The insulation should fit tightly and without gaps at all ells and tees, to prevent freezing and control conductive losses.

Because heat from the storage tank bleeds into the cold-water inlet main, it's best to insulate the cold-water line several feet back from the tank.

OVERHEATING PROTECTION

The temperature of a collector in full sun in a system that is not circulating its transfer fluid can reach 300° to 400° F. In summer, when the solar radiation is strongest and demand might be substantially less than the other seasons, the water heated by the system may approach the boiling point, 212° F. Neither of these overheating conditions is desirable; the second may be extremely dangerous. There are several pieces of equipment that should be on every solar water-heating system — pressure and temperature relief devices and mixing valves. These components will protect the system from damage caused by overheating.

STAGNATION

Stagnation is the condition of a collector in full sun when that collector is not being used to circulate fluid. Manufactured collectors will provide information on the ability of the collector to withstand stagnation. The stagnation temperature, typically 250° to 400° F, is determined by the construction of the collector, the amount of sun received, the ambient (outdoor air) temperature, and the system's other provisions for ameliorating overheating.

Two major hazards associated with stagnation are scaling and outgassing.

Scaling is the result of a chemical reaction between air in a drained collector and minerals and impurities in the water supply. It is encouraged upon each cycle of draining and filling, because new air is introduced as a facilitator of oxidation. The problem is worse where water supplies are hard, and less serious where water is softer. Scaling is one of the design weaknesses of open-loop draindown systems.

Outgassing is another hazardous result of stagnation temperatures. Outgassing occurs as a result of a chemical breakdown of the collector's insulation or the absorber's paint. Fiberglass insulation is held together and stays fluffy because an oil-based binder aids in those characteristics. At stagnation temperatures of 300° F or so, that oil vaporizes and condenses on the cover plate of the collector. This reduces transmissivity of the collector and reduces efficiency. It also damages the insulation, and in air systems, it introduces an undesirable gas into the air circulation.

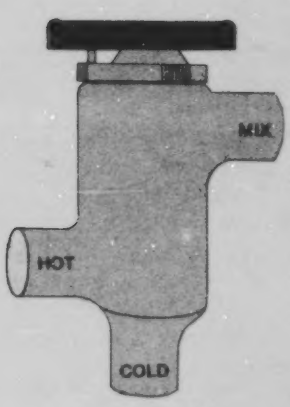
Owen-Corning Fiberglas, Inc. makes a low binder and a binderless fiberglass insulation. Polystyrene (commonly known as Styrofoam) begins melting at 168° F and is also unsuited for solar collector use. Polyisocyanurate (Thermax) insulation has a very high degradation temperature and does not pose outgassing problems.

Absorber paint (flat-black) can also be the cause of outgassing at stagnation temperatures, especially in homemade collectors. Barbeque black or paint especially made for high temperature applications will not outgas at stagnation temperatures, but ordinary spray paint will probably not do well under long exposures to intense heat.

MIXING VALVES

Mixing valves or tempering valves allow cold water to mix with overheated water to bring it back down to a safe, usable temperature.

They are necessary to temper the tank temperature, which could be 180° F, down to 120° or 130 ° F, a temperature that is adequate for hot-water needs. Temperatures above 120° F can be very dangerous — exposure to 160° F for several seconds may cause a third-degree burn to your skin or your child's. The mixing valve has a thermostatic setting, which can be set to the desired solar-tank outlet temperature. By allowing the tank to rise to a high temperature and tempering that water on its departure from the tank, you can harvest more Btu's than



a system that cuts off when the temperature reaches the service temperature. Mixing valves are a must in every system that does not have a thermostatic method of holding down tank temperatures.

TEMPERATURE AND PRESSURE RELIEF VALVES

Another safety component required for use as overheating protection is the temperature and pressure relief valve. A temperature and pressure relief valve should be installed on the tank at the top or at the hot-outlet line, and on the collector loop. The tank's temperature and

pressure relief valve may be rated 210° F, 150 pounds per square inch, which is probably what is on your water heater now. If you modify the plumbing to tee the hot water service line from the same port that serves the temperature and pressure relief valve, a long-stemmed valve will be required. Consistent with safe application in any system, the temperature and pressure relief valve should be drained safely into the house drain. A closed-loop system may be charged to about 15 pounds per square inch, and the temperature and pressure relief valve should be marked NOT POTABLE or DO NOT DRINK and should not have a threaded connection. Temperature and pressure relief on the loop of an open-loop system can be 210° F, 150 pounds per square inch because the loop is under street pressure.

EXPANSION TANK

All closed-loop systems must be outfitted with an expansion tank to allow for the liquid being more voluminous when heated than

when cool. Because temperature and pressure rise together, relieving a pressure buildup by allowing more volume alleviates a heat buildup problem. The most common expansion tank uses an impermeable diaphragm that will not allow liquid through and stretches convexly as the liquid expands, and contracts to a concave position when the liquid is cool. A two-gallon expansion tank is large enough for any domestic hot-water system.

EXPANSION CONNECTIONS AND HIGH-TEMPERATURE SOLDERING

The headers entering and leaving the collectors are subject to some extreme temperature changes, sometimes over a short period of time. Copper and aluminum both expand and contract quite a bit in going from one temperature extreme to the other, and should be designed to survive those temperature swings without leaking. Silver-solder, 95/5, should be used at the connections.

Flexible connections such as Hydro-flex (See Appendix C) offer additional expansion protection in systems with larger arrays. Expansion connections of that type also allow the tilt angle to be corrected seasonally, where a rack allows for tilt angle adjustment.

PURGE COILS

Purge coil loops may be added to a liquid collector system as an overheating remedy. Systems that employ distilled water or a refrigerant of some type as a heat-transfer fluid do not depend on temperature and pressure relief valves to dissipate summer heat because the temperature and pressure valves' action includes a loss of circulating fluid. It is these systems, especially, that use a purge coil to dump excess heat. The purge coil is a radiator-type heat exchanger, which is a loop properly and safely mounted outdoors. Indeed, an auto radiator with a fan would modify easily as a purge coil. If the loop can be built to be self-draining with the solenoid valve that stops its action, it can remain uninsulated. The purge coil loop is controlled by electric (solenoid) valves, which are wired to the differential thermostat. It is not a simple component, but it is effective, especially in space/water heating systems that overheat profusely in the summer.

DRAINDOWN AND DRAINBACK

When the storage tank is fully charged and there is still energy falling on the collector, boiling-over may be prevented by draining the collectors of the transfer fluid. Collectors may be drained by the disposition of the differential thermostat, much as freeze protection works. The collector then reaches stagnation temperatures empty rather than full. Although there is no problem of a drained collector boiling over, steel and aluminum absorbers are susceptible to scaling and corrosion when tap water and air mix in the collector. For this reason, draining systems should be limited to copper collectors and/or non-corrosive closed-loop heat-transfer fluids.

MINERALS COMPATIBILITY

Careful selection of your system's parts will assure harmonious performance. Dissimilar metals should be separated, to minimize electrolysis. There are several commonly-used solar system materials that are clearly incompatible:

* Cast-iron parts are incompatible with water loops.
* Stainless steel is incompatible with glycols; only cast-iron pumps should be used in those systems.
* Various transfer fluids are incompatible with some plastic washer and gasket parts.
* Some pumps and other parts tight enough to hold water may leak when used with thinner fluids.

Check the manufacturer's recommendations for parts compatibility, especially with plastic components.

INSTALLATION/CONSTRUCTION

The decision between home-built and commercial or dealer-installed systems is made by considering your carpentry and plumbing skills, your technical understanding and your resourcefulness at making things work. Certainly, the preheaters can be plumbed into an existing water system with a minimum of tools and special knowledge. The basic advantages of the owner-built system are:

(1) Half or more of the cost can be defrayed by doing your own work.

(2) It is easy to repair if you build it yourself.

(3) With enough information, you can fit your system to your own needs very closely.

There are some very real advantages to contracting with an installer to design and install your system:

(1) The installer should provide a warranty on parts and labor. Your unexpected problems are his problems; although not required by law, some service warranty should be offered.

(2) A package approach is less susceptible to component mismatching and may not require some of the monitoring components.

(3) The contractor-installed approach eliminates the need to rent, buy, or borrow tools you do not have.

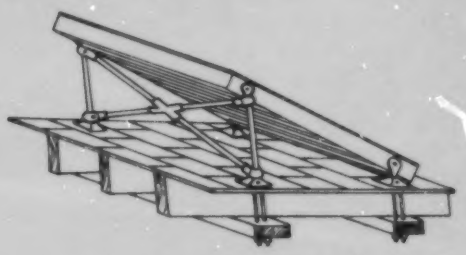
Both the homeowner-built and contractor-installed systems are cost effective when they replace electric or propane water-heating systems. Community-action agencies, economic development districts and vocational-technical schools all have solar projects in some areas. Check your telephone book Yellow Pages for these listings; see if your local agency or school has a solar water-heating program.

A building permit may be necessary for installations inside incorporated city limits. Check with City Hall to see what permit and inspection requirements apply to your town.

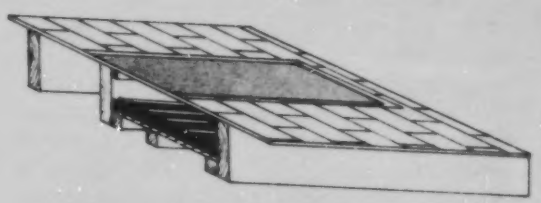
BUILDING CONSIDERATIONS

Most roofs that are retrofitted with a collector array will need some kind of structural supports added, to hold the weight of the collectors. Typically, this will be six to 10 pounds per square foot (psf). One way to make your roof more rigid is to add collar beams to the roof frame. A collar beam is a horizontal framing member that connects the roof rafters, making them more rigid. The collar beam will be more secure if it is bolted, but it may be nailed and glued.

A second method of increasing rigidity in the roof structure is by adding gussets to the rafters at the ridge joint. Gussets are plywood or wood pieces that strengthen the ridge joint by increasing the surface area of the bond between rafters. Gussets may be nailed and glued or bolted.



Braced Roof-Mounted Collector



Flush Roof-Mounted Collector

A stud or post may be added from the ceiling joists to the rafters as a third option for strengthening your roof frame. As with the other connections, the strength of the joint is assured by using a good carpenter's wood glue (aliphatic resin) and nails or bolts.

The roof penetration is made with flashing used for conventional vent pipe penetration. Liberal use of asphalt caulking or pitch is advised. A two-inch vent flashing will accommodate both the supply and return lines. You may fill the rest of the section with the asphalt caulk, making a pitch pocket.

There are many ways to secure the collectors to the roof but be sure to use an approach that will allow removal of the collectors for maintenance or replacement. The back of the

collector should be installed at least an inch and a half off the roof to eliminate potential moisture problems.

Storage tanks can add weight loads of up to 100 pounds per square foot to the frame on which it sits. You might have to consider a half-ton load caused by a 120-gallon tank, although your current 40-gallon tank will be fine anywhere. That weight is also on the insulation on the bottom of the tank, rendering it useless. A platform that would accommodate uncompressed insulation will reduce tank losses through the bottom. Conductive heat losses "pour" out of leaks, much like water leaks from a pipe, so the insulation on tanks and pipes should be carefully and tightly joined.

INSTALLING COMPONENTS

You will need a few basic plumbing tools to construct the collector loop — tube cutter, solder and a torch, and a couple of adjustable wrenches. Several of the components will work well only in particular positions. Read the data supplied with all instruments and pack it away carefully with your maintenance checklist for future reference. Here are a few ideas on component positioning:

* The pump should have a column of at least two feet of liquid immediately above it, to assure that it doesn't pump dry.
* The air vent must be plumb, or the float inside it will not float, and the air in the line will be trapped, not vented.
* All flowmeters have one and only one proper installed position. Be certain to follow the manufacturer's directions.
* Judicious but liberal use of unions can save you a lot of time and cut pipes later. They should be placed close to the inlet and outlet of the tank and collectors and near instruments and gauges.
* On closed-loop systems, make sure the temperature and pressure relief valve is safely drained, preferably into the house sewer or a storm drain. It should be unthreaded, and if it drains above ground it should be marked with warnings a child would understand.
* By using a level when you lay the piping runs, you can avoid high corners, which might trap air and build up pressure.

CHARGING THE CLOSED-LOOP SYSTEM

A newly-constructed system may be pressure-tested with air or with water, unless the heat-transfer fluid is incompatible with water. The system is charged at the low point with a temporary pump, which is drawing from a bucket. It is important that your bucket be clean, to keep the fluid free of impurities. Most differential thermostats have a manual override. Turn the pump on manually, and circulate for a few minutes. Drain the system and inspect for impurities. You are now ready for the final charge. The working pressure on a closed-loop system should be 15 to 20 pounds per square inch.

CHARGING THE OPEN-LOOP SYSTEM

An open-loop system may be charged by circulating supply water through the collectors while turning the pump on and opening the highest hot water faucet in the house. After the loop has quit venting air, the tank is full and the tap may be closed.

CHECKING THERMISTERS

The proper way to check a thermister is with an ohmmeter, but the function can be checked by reading thermometers you have installed, to see if the pump really starts and stops at the appropriate Δ t's. Apply ice to a draindown sensor to check that function.

MAINTENANCE CHECKLIST

Monthly:

- ★ Check penetrations, pipes, pumps, valves, etc., for leaks.
- ★ Check pressure in collector loop.
- ★ Check valve positions.
- ★ Read flowmeters and thermometers, and check controller functioning.
- ★ Inspect insulation for wear or separations.
- ★ Inspect absorber plate for deterioration.
- ★ Inspect collector sensor contact.
- ★ Wash collector covers if necessary.

Enter a balancing report into a logbook that includes all temperature, flow and pressure readings.

Semi-Annually:

- ★ Check color and specific gravity of transfer fluid. Replace or recharge as necessary but change glycols at least every two years.
- ★ Test solenoid valves.
- ★ Check roof and other structures for structural support.
- ★ Clean strainers.
- ★ Open and reset temperature and pressure relief valves.
- ★ Lubricate motors according to schedule.

TAX BREAKS AND INCENTIVES

You deserve a tax break for investing in a solar water-heating system. You get two tax breaks: a federal tax credit and a state tax deduction.

FEDERAL INCOME-TAX CREDIT

There are two different federal tax credits available, one for residential applications and one for businesses. To take advantage of these credits, complete IRS Form 5696, "Energy Credits". A credit reduces the tax owed or increases your refund.

The residential credit is 40 percent of the total installed cost, up to $4,000. In other words, the real cost of a $2,000 system is $1,200 after the tax credit is deducted.

The system must be:

(1) Installed on a principal residence (owned or rented) between January 1, 1980 and December 31, 1985;

(2) Constructed to last at least five years; and

(3) The taxpayer must be the first to use it.

The business credit for solar water heating systems is 15 percent. Utility companies and passive applications are not eligible. Business tax credits are non-refundable.

STATE INCOME-TAX DEDUCTION

Arkansas officials allow any taxpayer (individual, fiduciary, or corporation) a deduction from gross taxable income equal to the total cost of renewable-energy source expenses. If your taxable income on your form is $10,000 and you spent $2,000 building a solar water-heating system, then you pay taxes on an $8,000 income. That would be about $75 or $80 deducted from your state income tax payment. The tax dollar amount saved is even more impressive in higher income brackets.

RESIDENTIAL CONSERVATION SERVICES

The Residential Conservation Service is the program established by federal law (P.L. 95-619 Title II, Part 1.) It requires major utility companies to provide energy audits and arrangements for conservation and renewable

energy system financing to their customers.

Arkansas Power and Light Company, Southwestern Electric Power Company, Oklahoma Gas and Electric, Arkansas-Oklahoma Gas, Arkansas Western Gas, Arkansas-Missouri Power, Empire Gas, and Arkansas-Louisiana Gas Company are all required to provide home energy audits (sophisticated weatherization inspections) for a maximum fee of $15 to any homeowner requesting the audit. The fee is refundable. If the site is sufficiently free of shade, and if the economic analysis proves solar domestic hot-water feasible, which probably will be only in households now using electricity or propane to heat water, then the audit will recommend that such a system be installed.

Audits are available from major utilities through 1985. For further information about the Arkansas RCS program, contact the Arkansas Energy Office at 1-800-482-1122.

GLOSSARY

Absorber plate — The surface of a collector that receives and absorbs the sun's energy and transfers it to a circulating fluid.

Active systems — A system that requires external power to activate valves and/or circulate a heat-transfer fluid.

Ambient — Air surrounding an object, usually outdoor air surrounding the collector.

Btu — A British thermal unit; the amount of heat required to raise one pound of water one degree Fahrenheit.

Closed loop — A plumbing configuration that continuously recirculates the same fluid as a heat-transfer medium. A closed loop uses a heat exchanger to transfer heat to potable water supplies.

Collector (solar) — The furnace or energy receiver of a solar system. May be flat-plate, parabolic, concentrating, focusing, vacuum tube, greenhouse, etc.

Conduction — A form of heat transfer by the motion of adjacent molecules. Most commonly used describing heat transfer through a solid.

Convection — Heat transfer occurring by the motion of fluids from one place to another.

Delta t (Δ t) — Temperature difference. In solar hot-water systems, the temperature difference (Δt) between collector inlet and collector outlet is extremely important in assessing system performance.

Draw pattern — The rate of hot-water usage, the time of day of usage, and the time of solar gain considered together.

Ell — A plumbing part that makes a 90-degree turn in a line.

Glazing — 1) glass or fiberglass collector covers; or 2) putty-like compound that seals glass panels.

Heat capacity — The amount of heat a substance will store per Fahrenheit degree per volume unit (Btu/° F/ft³).

Heat exchanger — A device such as copper coil immersed in a tank or in a duct, which transfers heat from one fluid to another by conduction through the coil.

Heating degree-day — The difference in the daily average temperature and 65° F. A day with a 40° F average temperature would be a 25 degree-day day. A seasonal total of degree-days is a measure of the climate's severity.

Insolation — Incident solar radiation, radiation which strikes a surface, including direct, diffuse and reflected radiation.

Kilowatt hour (kwh) — Energy equivalent to 1000 watts of use for one hour or 3 413 Btu's.

Life-cycle costing — A method of determining value, in which long-term costs such as fuel costs and maintenance are included as factors, as well as initial cost.

Open loop — Systems that circulate potable water through the collectors and have a connection between the collector loop and storage.

Parasitic losses — Energy losses due to consumption by pumps, fans, electric valves or other externally-powered parts.

Passive systems — A solar system that requires no external power to collect or store solar energy.

Potable water — Water that is drinkable and is approved by the Arkansas Department of Health.

Retrofit — An application that is installed on an existing building.

Solar altitude — The angle from the sun to the horizon. That angle is 90° minus the latitude at solar noon on the equinoxes (March 21) and September 31), 90° minus latitude minus 23½° on the winter solstice (December 21), 90° minus latitude plus 23½° on the summer solstice (June 21).

Solar azimuth — The angle from the sun to due south.

Solar contribution — The percentage of total energy required by the system that is supplied by solar energy.

Specific heat — The amount of heat a substance will store per Fahrenheit degree per mass unit (Btu/° F/lb.).

Stagnation — A non-circulating condition that occurs when storage temperatures reach full capacity.

Tee — A plumbing fitting that splits a line into two openings.

Thermosiphon — The movement of a fluid upward as it becomes hotter and less dense. Allows passive circulation to transfer fluids if a tilted collector is placed at least two feet below storage.

Union — A plumbing fitting that disconnects lines and parts in convenient locations for maintenance purposes.

APPENDIX A

Worksheet One: For Water-Heating Load Calculation

	A Hot Gal Temp	– B Cold Inlet Temp	C ΔT	× D No. Days	× E No. Persons × 20	× F Heat Capacity H_2O	= G Load
Jan.	120	50	70	31	80	8.34	1.45×10^6
Feb.	120	50	70	28	80	8.34	1.31
Mar.	120	55	65	31	80	8.34	1.35
Apr.	120	60	60	30	80	8.34	1.20
May	120	70	50	31	80	8.34	1.04
June	120	75	45	30	80	8.34	.90
July	120	80	40	31	80	8.34	.83
Aug.	120	85	35	31	80	8.34	.72
Sept.	120	80	40	30	80	8.34	.80
Oct.	120	70	50	31	80	8.34	1.03
Nov.	120	60	60	30	80	8.34	1.20
Dec.	120	55	65	31	80	8.34	1.34×10^6
Annual							13.17×10^6

Derive column C by subtracting B from A.
C times D times E times F equals G, the load in Btu's/mo.

Worksheet Two: For Collector Efficiency Calculation

	A Temp. Inlet	B Avg. Temp. Amb.	C Avg.I/Hr.	D $\frac{Ti-Ta}{I}$	E Avg. Hdy. Efficiency
Jan.	110°F	39	190	.37	.33
Feb.	110°F	43	232	.29	.42
Mar.	110°F	50	248	.24	.47
Apr.	110°F	62	250	.19	.53
May	110°F	70	249	.16	.57
June	110°F	78	273	.12	.61
July	110°F	81	271	.11	.62
Aug.	110°F	81	274	.11	.62
Sept.	110°F	73	243	.15	.59
Oct.	110°F	62	250	.18	.54
Nov.	110°F	50	197	.30	.40
Dec.	110°F	42	181	.37	.33

A is selected by the designer.
B is extrapolated from National Oceanic & Atmospheric Administration Climatological Data for Arkansas, VOL. 84, No. 13, LR FAA Station.
C is extrapolated from **Solar Radiation For The State of Arkansas**, University of Arkansas, Turner/Battle.
D equals A minus B divided by C.
E is based on $F_R U_L = 1.27$, 7gpm flow rate.

Worksheet Three: For Calculating Percentage of Solar Contribution

	A Insolation/ 100 Sq. Ft.	B Collector Efficiency	C System Efficiency	D Delivered Heat	E Load In BTU's	F Solar Contribution
Jan.	3416200	.33	.60	.68 × 10^6	1.45 × 10^6	.47
Feb.	3897600	.42	.60	.98	1.31	.75
Mar.	4448500	.47	.60	1.25	1.35	.93
Apr.	4844000	.53	.60	1.48 (1.20)	1.20	1.00
May	4594200	.57	.60	1.57 (1.04)	1.04	1.00
June	4929000	.61	.60	1.80 (.90)	.90	1.00
July	5043700	.62	.60	1.88 (.83)	.83	1.00
Aug.	5039500	.62	.60	1.90 (.72)	.72	1.00
Sept.	4371000	.59	.60	1.55 (.80)	.80	1.00
Oct.	4566300	.54	.60	1.48 (1.03)	1.03	1.00
Nov.	3594000	.40	.60	.86	1.20	.72
Dec.	3193000	.33	.60	.63	1.34	.47
Annual	51797000	.50	.60	10.92 × 10^6	13.17 × 10^6	.83

A is based on Region II, Little Rock.
A times B times C equals D.
B is derived from Worksheet Two.
D divided by E equals F.
D cannot be larger than E.
C assumes 20 percent loss, 10 percent parasitic loss, 10 percent line loss.

Worksheet Four

	A Heat Delivered By 25 Sq. Ft.	B Load	C Solar Contribution	D Heat Delivered By 50 Sq. Ft.	E Load	F Solar Contribution	G Heat Delivered By 75 Sq. Ft.	H Load	I Solar Contribution
Jan.	.17 × 10^6	1.45 × 10^6	.13	.34 × 10^6		.26	.51 × 10^6		.35
Feb.	.25	1.31	.19	.50		.38	.74	SAME	.49
Mar.	.31	1.35	.23	.63		.48	.94		.82
Apr.	.37	1.20	.31	.74	SAME	.62	1.11	AS	.93
May	.39	1.04	.38	.79		.74	1.18 (1.04)		1.00
June	.45	.90	.50	.90	AS	1.00	1.35 (.90)	COLUMN	1.00
July	.47	.83	.57	.94 (.83)		1.00	1.41 (.83)		1.00
Aug.	.43	.72	.60	.85 (.72)	COLUMN	1.00	1.28 (.72)	B	1.00
Sept.	.39	.80	.49	.78		.98	1.17 (.80)		1.00
Oct.	.37	1.03	.36	.74	B	.72	1.11 (1.03)		1.00
Nov.	.22	1.20	.18	.43		.36	.65		.55
Dec.	.16	1.34	.12	.32		.24	.48		.36
Annual	3.98 × 10^6	13.17 × 10^6	.30	7.72		.59	9.75	13.17 × 10^6	.74

A divided by B equals C.
D divided by E equals F.

Worksheet Five: For Sizing Economics

Collector Area	A Annual Solar Contribution	B Annual Load	C Energy Cost Per Unit	D Annual Return	E System Cost	F Payback in Years
25 Sq. Ft.	.30	3858	.07/kwh	$ 81.02	$ 750	9.3
50 Sq. Ft.	.59	3858	.07	159.34	1000	6.3
75 Sq. Ft.	.74	3858	.07	199.84	1250	6.2
100 Sq. Ft.	.83	3858	.07	224.15	1500	6.7

Assumptions:
Load = 13.17 × 10^6 Btu/yr.
= 13 MCF Natural gas × 65 percent efficiency = 20 MCF (1 MCF = 1.03 × 10^6 Btu).
= 3858 kwh electricity (1 kwh = 3413 Btu).
= 137 gallons Propane × 65 percent efficiency = 211 gallons (1 gallon = 92,000 Btu).

A is derived from Worksheets Three and Four.
B is derived from Worksheet One. (annual load ÷ 3413)
A times B times C equals D.
D divided by E equals F.

Worksheet Six: For Water-Heating Load Calculation

	A Hot Out Temp	—	B Cold Inlet Temp	C ΔT	×	D No. Days	×	E No. Persons × 20	×	F Heat Capacity H_2O	=	G Load
Jan.	120					31				8.34		
Feb.	120					28				8.34		
Mar.	120					31				8.34		
Apr.	120					30				8.34		
May	120					31				8.35		
June	120					30				8.34		
July	120					31				8.34		
Aug.	120					31				8.34		
Sept.	120					30				8.34		
Oct.	120					31				8.34		
Nov.	120					30				8.34		
Dec.	120					31				8.34		

Derive column C by subtracting B from A.
C times D times E times F equals G, the load in Btu's/mo.

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Worksheet Seven: For Calculating Percentage of Solar Contribution

	A Insolation/100 Sq. Ft.	B Collector Efficiency	C System Efficiency	D Delivered Heat	E Load in BTU's	F Solar Contribution
Jan.		.33	.60			
Feb.		.42	.60			
Mar.		.47	.60			
Apr.		.53	.60			
May		.57	.60			
June		.61	.60			
July		.62	.60			
Aug.		.62	.60			
Sept.		.59	.60			
Oct.		.54	.60			
Nov.		.40	.60			
Dec.		.33	.60			
Annual		.50	.60			

A is derived from Figure 1 and the map.
A times B times C equals D.
B is derived from Worksheet Two.

D divided by E equals F.
D cannot be larger than E.
C assumes 20 percent loss, 10 percent parasitic loss, 10 percent line loss.

Worksheet Eight

	A Heat Delivered By 25 Sq. Ft.	B Load	C Solar Contribution	D Heat Delivered By 50 Sq. Ft.	E Load	F Solar Contribution	G Heat Delivered By 75 Sq. Ft.	H Load	I Solar Contribution
Jan.	$.17 \times 10^6$			$.34 \times 10^6$			$.51 \times 10^6$		
Feb.	.25			.50			.74		
Mar.	.31			.63			.94		
Apr.	.37			.74	SAME		1.11	SAME	
May	.39			.79			1.18 (1.04)		
June	.45			.90	AS		1.35 (.90)	AS	
July	.47			.94 (.83)			1.41 (.83)		
Aug.	.43			.85 (.72)	COLUMN		1.28 (.72)	COLUMN	
Sept.	.39			.78			1.17 (.60)		
Oct.	.37			.74	B		1.11 (1.03)	B	
Nov.	.22			.43			.65		
Dec.	.16			.32			.48		
Annual	3.98×10^6			7.72			9.75		

A divided by B equals C.
D divided by E equals F.

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Worksheet Nine: For Sizing Economics

Collector Area	A Annual Solar Contribution	B Annual Load	C Energy Cost Per Unit	D Annual Return	E System Cost	F Payback in Years
25 Sq. Ft.						
50 Sq. Ft.						
75 Sq. Ft.						
100 Sq. Ft.						

Assumptions:
Load = 13.17 × 10^6 Btu/yr.
= 13 MCF Natural gas ÷ 65 percent efficiency = 20 MCF (1 MCF = 1.00 × 10^6 Btu).
= 3858 kwh electricity (1 kwh = 3413 Btu).
= 137 gallons Propane ÷ 65 percent efficiency = 211 gallons (1 gallon = 92,000 Btu).

A is derived from Worksheets Three and Four.
B is derived from Worksheet One. (annual load ÷ 3413)
A times B times C equals D.
D divided by E equals F.

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APPENDIX B

ARKANSAS SOLAR WATERHEATING DEALERS/INSTALLERS

Solar Shop of Paragould — *Solar Unlimited*
Route 4, Box 211
Paragould, AR 72450
(Bob or Pat Lee) 239-4777

Benton Taylor & Assoc — *Thermal Storage Rod, Solara Collectors*
P.O. Box 67
Sparkman, AR 71763
678-2279

Solar Supply — *American Solar King*
1200 West Main
Russellville, AR 72801
(Sam Campbell) 968-7341

Jim Harm, Solar Inc — *American Solar King*
5301 McClanahen
North Little Rock, AR 72118
758-0556

Natural Environments — *U.S. Solar, Solaroll*
1717 Rebsamen Park Road
Little Rock, AR 72202
(Bill Ball) 664-7217

North Central Energy Service — *American Solar King, Yazaki*
P.O. Box 309
Clinton, AR 72031
(Bill Tilson) 745-2484

Voss Central Air Conditioning — *Lennox*
7225 West 12th
Little Rock, AR 72204
(Mike Voss) 664-9180

United Soltec — *American Solar King*
5301 McClanahen, B-7
North Little Rock, AR 72116
(Chuck Davis) 771-1700

International Solar Inc — *American Solar King*
5301 McClanahen, B-7
North Little Rock, AR 72116
(Duke Nix) 753-8410

Advanced Solar Systems — *A. O. Smith*
5301 McClanahen, A-2
North Little Rock, AR 72116
(Bill Grant) 753-8410

Stitt Energy Systems — *U.S. Solar Corp.*
1301 South 8th Street
Rogers, AR 72756
(Orlo Stitt) 636-8745

Pine Bluff Heating & Air Conditioning — *Mor-Flow Systems and Components*
605 East 6th
Pine Bluff, AR 71601
(Kenneth Scott) 536-3998

Solencon — *Southeastern Solar System, Faico*
202 Country Club
Sherwood, AR 72116
(John Crum) 835-4090

APPENDIX C

OUT-OF-STATE MATERIALS SUPPLIERS

GENERAL:

California Solar Distributors
523 Weddell Drive
Sunnyvale, Ca 94086

People's Solar Sourcebook
S.U.N.
Box 306
Bascom, OH 44809 ($5.00)

Solar Contact Systems
1415 Vernon Street
Anaheim, CA 92805

DRAINDOWN VALVES
(Electric Solenoid Valve):

Sunspool
439 Tusso St.
Palo Alton, CA 94301

California Solar
532 Weddell Drive
Sunnyvale, CA 94086

ETHYLENE PROPYLENE DIENE MONOMER:

Sun Roll
1169 Cross Street
Cotuit, MA 02635

ABSORBER PLATES:

Olin Corporation/Brass Group
East Alton, IL 62024

Phelps Dodge Brass Co.
300 Park Ave.
New York, NY 10022

Terra-Light, Inc.
30 Manning Road
P.O. Box 493
Billetica, MA 08121

INSULATION — SOLAR:

Owens-Corning
2805 B Lincoln Ave.
Evansville, IN 47714

FLOWMETERS:

Blue-White Ind.
14931 Chestnut Street
Westminister, CA 92683

ULTRAVIOLET PROTECTION:

Kalwall Corporation
P.O. Box 237
Manchester, NH 03105

FLEXIBLE CONNECTORS:

Hydroflex Corporation
2101 NW Brickyard
Topeka, KS 66618

ELAPSED-TIME METERS:

Allied Electronic
401 E. 8th Street
Ft. Worth, TX 76102

SELECTED BIBLIOGRAPHY

Solar Heating and Cooling of Residential Build- Sizing, Installation and Operation of Systems, Solar Energy Applications Laboratory, Colorado State University, USGPO Stock No. 003-011-00085-2, October, 1977.

Converting a Conventional Electric Water Heater to a Solar Storage Tank, Douglass E. Root, Florida Solar Energy Center, September, 1980.

Solar Heating Design By The F-Chart Method, Beckman, Klien, Duffie, John Wiley & Sons, 1979.

Solar Radiation for the State of Arkansas, W. D. Turner and I. H. Battle, Jr., University of Arkansas for the Arkansas Department of Energy, September, 1980.

Climatological Data, Annual Summary, Arkansas, 1979, National Climatic Center, Asheville, North Carolina.

Inexpensive Monitoring of Solar Domestic Water Heater Performance, W. R. McCluney, Florida Solar Energy Center, July, 1980.

Solar Age Magazine, Solar Vision, Inc., May, 1980.

Installation Guidelines for Solar DHW Systems, Franklin Research Center, Philadelphia, Pennsylvania, under contract H-2377; order from Supt. of Documents, USGPO, Washington, D.C. 20402.

ENERGY FACT SHEET

SOLAR WATER HEATERS CONSUMER TIPS

What Is a Solar Water Heater?

A residential solar water heater collects solar energy and transfers this energy, in the form of heat, to a home's water supply. Usually a solar water heater does not replace a gas or electric water heater but rather reduces the need to use the conventional water heater.

A typical solar water heater system consists of a collector, a distribution system, a storage tank, a control system, and an auxiliary water heating system. The collector absorbs available solar energy and uses the distribution system to transfer this energy to the hot water storage tank. The control system determines when to transfer the solar heat from the collector to the storage tank. The auxiliary water heating system is a conventional water heater that supplements the solar system as necessary in order to maintain a constant supply of stored hot water.

Should I Consider Buying a Solar Water Heater?

Solar water heaters can save money. The basis for the decision to buy a solar water heater should be the relationship between how much money it will save compared to what it will cost. One way to make this comparison is to view the purchase of a solar water heater as an investment and the hot water cost savings as a return on the investment. Recent studies have shown that the average return on investment for currently available solar water heaters is from 9 to 18 percent.

The return on investment of a solar water heater is found by dividing the yearly hot water cost savings that result from using the system by the cost of the system. The savings in hot water costs depend on three factors – the amount of energy the solar system will supply, the amount of hot water a family uses, and the current utility rate. A solar contractor will be able to estimate the amount of energy supplied by his particular system, a value often called the Solar Savings Fraction. The Solar Savings Fraction usually will be between 50 to 80 percent of the total hot water load.

The second factor – hot water usage – varies widely from family to family. Table 1 lists various hot water uses and the normal hot water consumption for each. These figures can be used to calculate weekly hot water consumption. To find current hot water costs, divide the weekly consumption by seven to find average daily usage. This value can then be used in Table 2 to give an estimate of current annual hot water costs under the applicable utility rate. (Current utility rates are normally stated in utility bills.) To find out how much the solar system will save in hot water costs a year, multiply the current annual cost of hot water by the Solar Savings Fraction of the solar water heater being considered.

Table 1. Hot Water Uses

Hot Water Uses	# of Gallons
—Shower	12-15/use
—Bath	15-20/use
—Automatic Dishwasher	12-15/use
—Manual Dishwashing	4-6/use
—Clothes Washing	
Hot Cycle	16-24/use
Warm Cycle	10-15/use
—Other (cleaning, sinks, food preparation, etc.)	3-6/day

Directions:

1) Determine the number of times in a week each of the hot water uses occurs.
2) Find the appropriate number of gallons for each use and add all values to get a total weekly hot water consumption.
3) Divide by seven to get the average daily consumption and use this value in Table 2.

For example, a family using 560 gallons a week or, dividing by seven, 80 gallons a day with an electric water heater will have an estimated annual hot water cost of $390 if their utility rate is 6¢/kWh. If a dealer can provide a system with a 70 percent Solar Savings Fraction, then the annual dollar savings will be $273 ($390 x 70%).

The final step – comparing these savings with the cost of the system – is made by subtracting any tax incentives (i.e., 40% for the federal tax credit) from the cost of the system and dividing that number into the annual dollar savings. For example, if the installed cost of the system is $3000, the federal tax credit will be $1200 ($3000 x 40%), and thus the effective cost is $3000 minus $1200, or $1800. Dividing this number into the annual hot water cost savings ($273 ÷ $1800) gives .152 or 15.2% annual return on investment. This figure can then be compared to other investments to determine whether a solar system is a worthwhile purchase.

Is My House Suitable for a Solar Water Heater?

There are three major areas of concern in determining whether a house is suitable for a solar water heater installation. They are collector placement, storage tank placement, and the distance between the two. The best location for the collector is usually the roof of the house. The roof should face within 15 degrees of due south and be exposed to direct sunlight between 9 a.m. and 3 p.m. throughout the year. The collector should be tilted at an angle within 10 degrees of the local latitude. For example, at latitude 33°, the collector should be tilted within 23° to 43°. When the roof does not have sufficient slope, a mounting frame can be used to raise the collector panels to the appropriate angle. The collector can also be mounted on the ground. However, ground-mounted collectors are more susceptible to shading and damage than those located on the roof.

The solar storage tank is usually located close to the conventional water heater. Keep in mind that a solar storage tank is larger and takes up more space

than a conventional water heater. Another factor in determining whether a house is suitable for the installation of a solar water heater is the distance between the storage tank and collectors. Excessively long pipe runs can be expensive to install and will increase distribution heat losses, thus lowering the amount of useful solar energy available for heating water.

What Types of Solar Water Heaters Are Available?

Residential solar water heaters can be divided into two different design types – direct and indirect systems. Direct systems circulate the domestic water supply through the collectors where it is heated directly by the sun. Indirect systems separate the domestic water supply from the fluid in the collector loop and use a heat exchanger to transfer the heat from the collector fluid to the water supply.

Freeze protection is also used to classify system types. Draindown and drainback designs drain the water from the collectors and distribution system exposed to outside temperatures in order to prevent freezing. The draindown system drains the exposed piping and collectors by means of activating an automatic dump valve when freezing temperatures are sensed by the controller. However, experience has revealed that the automatic valve on some systems can be unreliable at times, resulting in freeze damage. Consequently, this valve should be checked when freezing temperatures occur. With the drainback design, no automatic valves are required because gravity drains the water in the collectors and exposed piping to a reservoir tank every time the circulating pump is turned off. If the planned location for the solar water heater does not allow for a gravity drain option, the draindown and drainback designs should not be considered.

Recirculation systems prevent freezing by circulating hot water from the storage tank through the distribution system and collectors when freezing temperatures occur. In locations where freezing occurs frequently, the recirculation system should not be used because there will be excessive heat losses from recirculating the hot water to prevent freeze damage.

Antifreeze indirect systems use an antifreeze solution in the exposed piping and collectors, lowering the fluid freezing point to safe levels. Normally, the antifreeze solution consists of a mixture of propylene glycol and water. However, silicone or other fluids that are not subject to freezing may also be employed.

Thermosiphon and bread box solar water heaters have no automatic freeze protection since they have no mechanical parts. If used in cold climates, these systems should be manually drained in winter months.

Table 2. Annual Energy Costs for Domestic Water Heating

Daily Usage[a]	Utility Rates[a] Electric ($/kWh) .05	.06	.07	.08	.09	.10	Natural Gas ($/Therm) .40	.50	.60	.70	.80
20 gal/day	$123[b]	148	173	198	222	247	$52[bc]	65	78	91	104
35 gal/day	174	208	243	278	313	347	73	91	109	128	146
50 gal/day	224	269	313	358	403	448	94	118	141	165	188
65 gal/day	274	329	384	438	493	548	115	144	173	201	230
80 gal/day	324	389	454	519	583	648	136	170	204	238	272
95 gal/day	374	449	524	599	674	749	157	197	236	275	314
110 gal/day	424	509	594	679	764	849	178	223	267	312	357
125 gal/day	475	570	665	759	854	949	199	249	299	349	399

NOTES:

a. If the daily usage calculated from Table 1 or current utility rate falls between the values shown, interpolation will be necessary to find actual annual hot water costs.

b. Annual Energy Cost = Annual Energy Load x Utility Rate,
where: outlet water temperature = 140°F,
inlet water temperature = 65°F, and
tank heat losses = 3.1 kWh/day.

c. Combustion efficiency of gas burner is assumed to be 65%.

What Are a System's Maintenance Requirements?

Experience has shown that one of the most important steps in maximizing potential energy savings with solar systems is to provide good maintenance. System maintenance requirements will vary according to the solar water heater design, and the solar contractor should provide the homeowner with complete instructions on maintenance procedures. Also, the listing of equipment specifications from manufacturers should include the required maintenance for each item installed. Regular system maintenance will be required no matter what type of system is selected.

For example, periodic cleaning of the collector glazing is necessary to maintain good performance. Flushing the distribution system and storage tank to remove sediment, protecting pipe insulation, and oiling pumps are other maintenance tasks which can assure good system performance. If an antifreeze system is used, the dealer should be asked to specify the type and brand of the antifreeze, as well as required maintenance procedures to ensure that the mixture retains its original properties and does not deteriorate over time. In the case of system malfunction, or other event, which results in overheating of glycol-based antifreeze fluid in the collector loop, it is important that the fluid be checked or replaced. This will help prevent any corrosion which might occur as a result of a change in properties of the fluid.

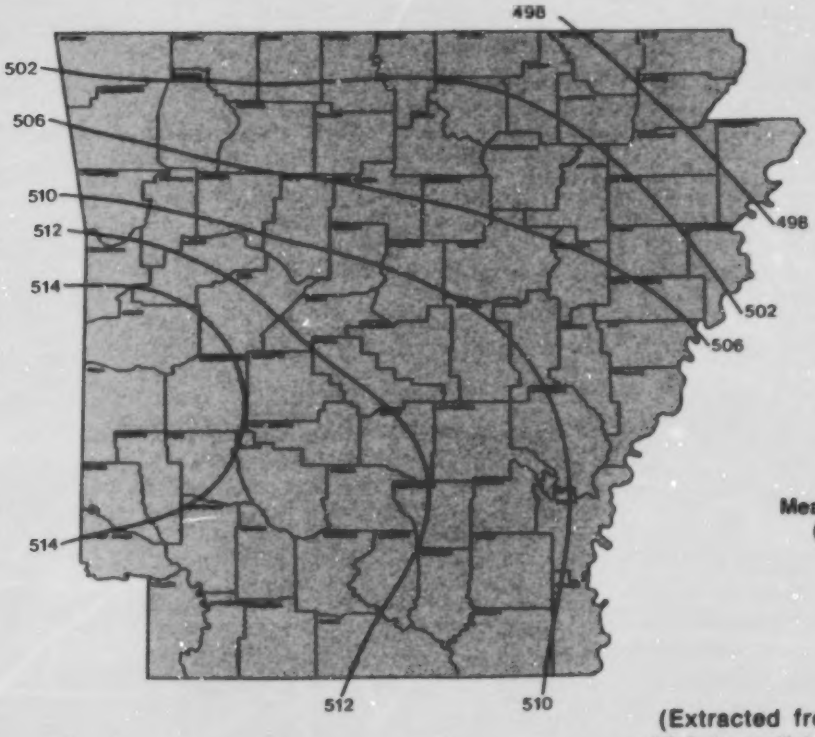
Should I Buy a Solar Water Heater?

The decision on whether to buy a solar water heater deserves the same careful consideration as any other major purchase. The purchase decision should include determining whether a solar water heater is a good investment, assessing the suitability of the site, and researching currently available system types. The homeowner should become as knowledgeable about these subjects as possible in order to make an informed decision about buying a solar water heater.

If a solar water heater seems to be a worthwhile purchase, the next step is to select a competent solar equipment contractor. To find a solar contractor, locate as many local contractors as possible in order to get competitive prices and services. Require that the contractors provide a list of recent customers and talk to them. Also, obtain a written contract to make sure that the written warranty covers the contractor's work as well as equipment. The solar contractor should also offer a complete system operation manual at the time of installation that describes normal system operation, equipment specifications, emergency shut down procedures, and maintenance requirements.

Arkansas Climate Atlas

The solar radiation data presented herein should exemplify typical solar radiation values for the state of Arkansas. However, due to the nature of solar radiation, large variations can occur on a monthly or yearly basis. Monthly differences in total solar radiation values might vary ± 30 percent for the winter months. Up to ± 15 percent differences from the average values might be expected for the summer months. Thus, on a monthly basis, variations of these magnitudes from year to year can be expected for the solar radiation values given in this report. Though these variations do exist, it is believed that the values of solar radiation do represent long-term averages which can be used both to size solar energy systems and to evaluate their expected long-term performance.



Mean Annual Total Solar Radiation
(Thousands of Btu's per Ft²)

(Extracted from *Arkansas Climate Atlas*, which is available from the Arkansas Energy Office.)

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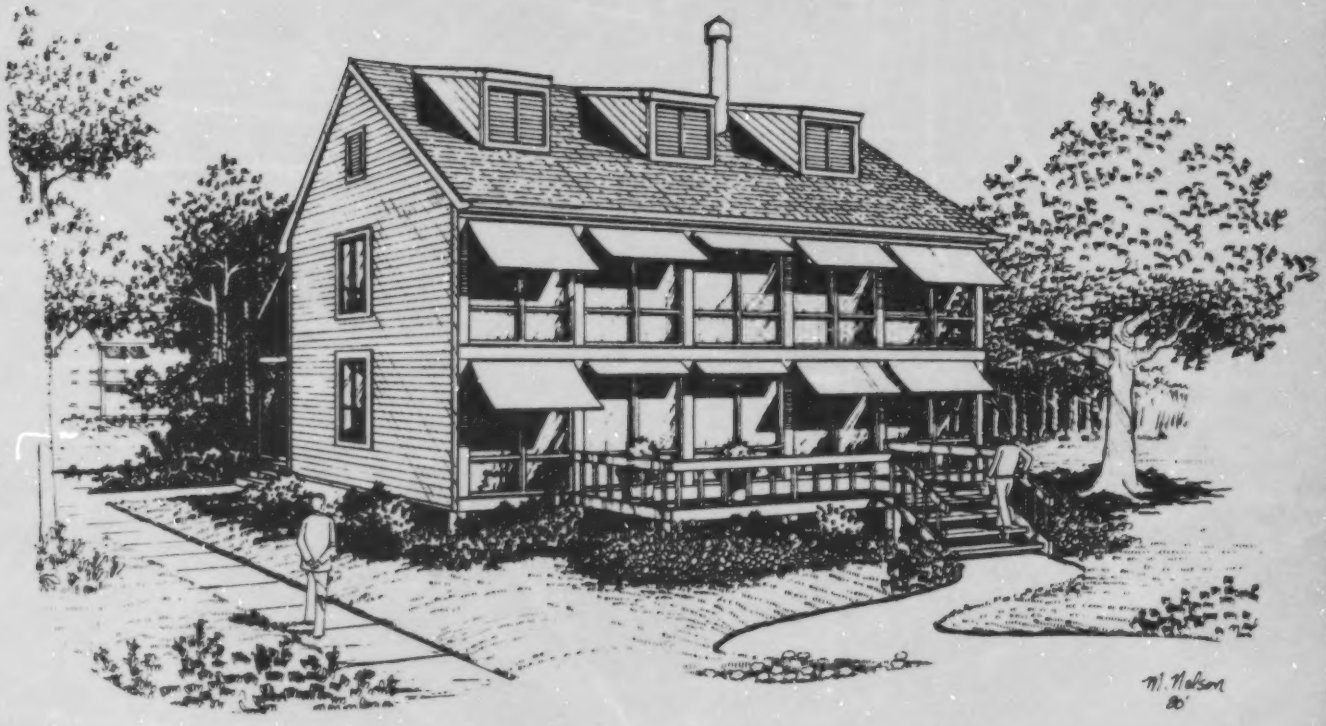
4 Passive Solar Energy



SOLAR HOMES FOR ARKANSAS

A plan book of energy efficient designs
with performance analysis

STATE OF ARKANSAS
OFFICE OF THE GOVERNOR
State Capitol
Little Rock 72201

Bill Clinton
Governor

Dear Arkansans:

The near panic that succeeded the Arab oil embargo in 1973 bred a national energy policy designed to make the United States energy independent by 1980. Significant progress was made during the seventies toward that goal. National energy use in 1981 was actually less than in 1973.

Before we applaud ourselves too much, however, it must be remembered that the Nation has only a finite supply of non-renewable energy resources. Therefore, the policy for the eighties must once again aggressively promote the efficient use of renewable and non-renewable energy resources. Energy efficiency in economic terms means getting the most for your energy dollar -- never has this been more important. Increased efficiency in consuming non-renewable energy resources and promotion of cost effective technologies in renewable energy resources are major goals for the eighties.

The passive solar designs chosen for this publication, when properly sited, are practical, cost effective designs that can help move you, our State, and our Nation closer to a goal of energy independence.

Sincerely,

Bill Clinton

BILL CLINTON
Governor

Introduction

Solar Homes for Arkansas has been produced to offer Arkansas residents plans for energy-efficient passive solar homes specially adapted to the heating and cooling requirements of the state. Passive solar design offers homeowners and builders houses that both conserve and produce energy, houses that are comfortable and attractive to live in and at the same time economical to operate due to lower energy consumption. This plan book is intended to make this innovative technology easily accessible to Arkansans interested in energy-efficient housing.

All of the homes included in this collection have been carefully evaluated to assure quality in both overall design and energy features. They have been selected to represent a wide price range so that a passive home is offered for almost every budget. Each house in this plan book is accompanied by a description of its passive solar features and its projected performance compared to a home of the same size and general design without passive solar features. This gives the prospective builder a basis for comparing passive homes to conventional ones.

A balance between heating and cooling needs has been strongly emphasized in the designs. The nature of the Arkansas climate requires a careful approach to passive solar heating, since faulty design or sizing of a passive system can cause summer overheating. Not only would this create an uncomfortable living environment, but it would cancel out the net energy gain of the solar system with increased air conditioning costs.

Several of the plans in the book were developed under passive solar design programs conducted by the Southern Solar Energy Center between 1979 and 1981 under the sponsorship of the U.S. Department of Energy. These programs drew heavily on the experience of local designers, builders, and Realtors in southern cities to produce houses that stressed marketability along with energy performance. Consequently, the homes included resemble popular conventional houses and should blend well in existing neighborhoods and new developments.

Passive solar design has advanced rapidly in the last few years. Passive houses have been refined and tested and their actual performance compared with performance predictions. To ensure good performance, the homes included in this book incorporate passive systems that have been tested and proven in numerous applications for several years. All the homes incorporate conventional heating and cooling systems along with the solar systems so that the homeowner has the complete flexibility to adjust the home's comfort level and to choose the degree to which the passive system is relied on.

A brief discussion of passive solar design principles precedes the house plans. The selection and landscaping of the home's site also is discussed in its relationship to solar design. The builder or homeowner interested in obtaining more detailed information on either of these subjects will find several good reference sources in local bookstores and libraries.

Passive solar design is ready now to help alleviate the homeowner's burden of high energy costs. It is hoped that by providing plans for passive solar homes, builders and homeowners in Arkansas will be able more easily to take advantage of this energy-saving technology.

Passive Systems

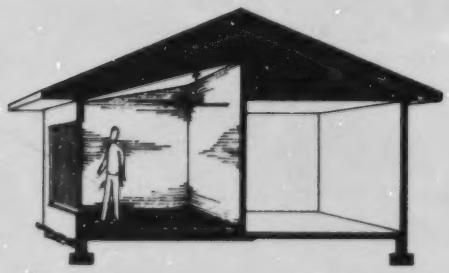
A passive solar home employs structural elements to collect, store, and distribute heat from the sun. The basic components of the solar heating system are familiar parts of the house: the solar collector can be a glass window, door, or skylight; heat storage mass can take the form of masonry or concrete elements, such as a brick fireplace or a tiled floor; and the heat distribution system can consist of doors or operable vents. Thus, the appearance of a passive solar home may differ little from that of a conventional home. The big difference shows up in lower heating bills.

How much energy does a passive home save? Each of the plans in this book includes a description of the home's estimated energy consumption compared to a home of the same size without solar features. Savings range from 30 to 60 percent. However, actual energy savings are difficult to predict accurately because of variations in individual energy use patterns and standards of comfort. Savings may be greater or smaller depending on the homeowner.

There are several types of passive systems, but three main types are represented in the house plans in this book: direct gain, mass wall, and sunspace systems. Each employs the three basic elements common to passive systems – collector, storage mass, and a means for heat distribution – but in different configurations.

Direct Gain

A direct gain passive solar system consists of large window areas on the south side of the house. Solar radiation passes through the windows and into the living space where it strikes walls, floors, ceilings, and objects in the room. Some of this heat is convected away from these surfaces and warms the air inside the room. Some of it is absorbed by these objects and then released when room temperatures fall.

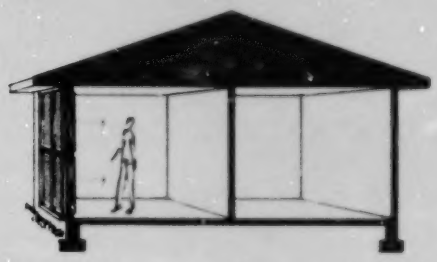


How much heat is stored depends on the nature of the objects the solar radiation strikes. Light-colored objects reflect solar radiation. Dark-colored objects absorb it. Massive objects, such as a brick wall or fireplace, absorb and retain more heat than lightweight objects, such as fabrics or carpets.

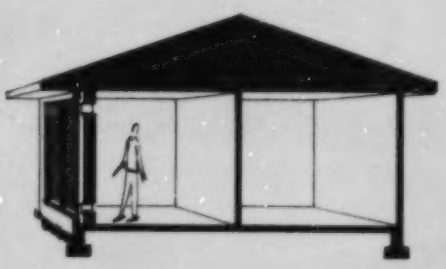
Direct gain systems are the simplest and least costly of all passive solar systems. Incorporating a direct gain system in a house design can be as simple as rearranging windows to position more of them on the south side and fewer on the east, west, and north sides. Besides providing a portion of the home's heat, the abundance of south-facing windows also provides natural lighting throughout the day.

Mass Wall

A mass wall passive solar system consists of vertical south-facing glass and an adjacent wall of a massive material, such as masonry, concrete, or containers of water. In this type of passive system the storage mass is between the glazing and the living space rather than in the living space. Solar radiation strikes the glass and is absorbed by the surface of the mass wall and stored. When the temperature in the adjacent space drops below that of the wall, the wall releases its heat.



Water Wall



Trombe Wall

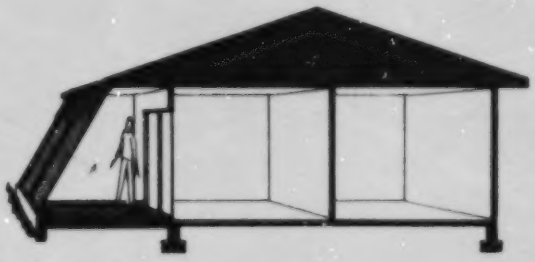
Two commonly used types of mass walls are: Trombe walls and water walls. In a Trombe wall system, the mass wall is concrete or masonry. In a water-wall system, it consists of containers of water. The choice of one type of mass wall over another is based on where the wall is to be located in the house and which type is more practical for that location. Mass walls are well suited to situations where privacy or noise is a concern, such as in urban settings where a south wall adjoins a busy street.

Sunspace

A passive sunspace is a separate room attached to the south side of a house that acts as a solar collector. It has large expanses of south-facing glass and may include thermal storage mass in the form of masonry floors and walls or sometimes containers of water.

The sunspace operates in much the same way as a direct gain system. Solar radiation enters the space through the glazing and heats the air in the space. Some of the heat is absorbed by thermal storage mass. An air circulation system moves warm air from the sunspace into the house during the winter. A venting system removes heat from the sunspace and vents it to the outside during the summer.

Unlike direct gain systems, which are part of the main living space, the sunspace can be isolated or shut off from the house. This means that daytime overheating or nighttime temperature drops have little effect on the home's interior temperature. The sunspace is also an attractive additional living area in the home and can be put to a variety of uses.



Special Considerations

Solar houses entail some special considerations beyond those normally encountered in selecting and building a conventional house. These relate primarily to climate, summer shading, and weatherization.

Climate

Passive solar houses must be tailored to specific climates in order to function properly. The ratio of glass to thermal storage mass and of the size of the passive system to the size of the house changes for various locations. The type of system used can vary too, especially in southern climates where overheating can be a problem. Therefore, it is important in selecting a passive solar house to be certain that it has been designed for the climate in which it will be built.

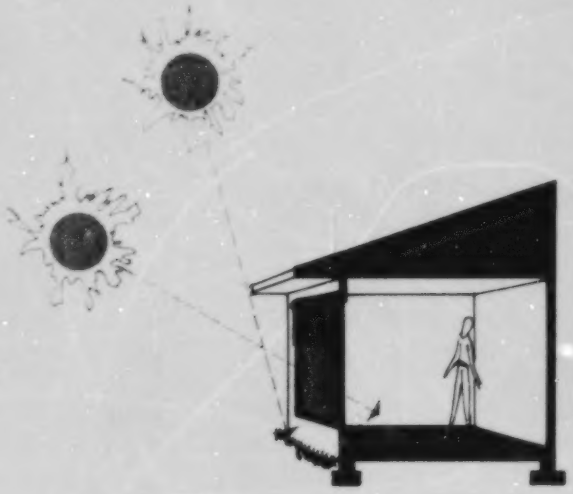
Climate must also be considered at a local level. Two towns in the same state can have completely different heating and cooling requirements depending upon prevailing weather patterns and geographical features. Even two sites in the same city can have different requirements.

Insulation and Weatherization

Like any other house, a passive house must incorporate good energy conservation features. Specifications for the homes in this plan book call for infiltration control techniques and insulation levels appropriate to this state. Unless these energy-saving features are incorporated, much of the energy produced by the passive system will be wasted.

Summer Shading

The importance of summer shading cannot be overemphasized. A passive system provides heat in winter and will go on providing heat in summer unless measures are taken to keep the heat out. Most of the houses in this plan book incorporate overhangs for sun control. These are sized to admit the low winter sun but block the high summer sun. However, overhangs deal only with direct sunlight, which is often less than half of the total solar radiation reaching the passive solar collector. Indirect sunlight reflected off nearby surfaces or diffuse radiation from a hazy summer sky will continue to strike the passive system unless some sort of exterior shading device is used, such as operable shutters, blinds, or shades.



Shading: *Summer shading is critical in passive solar systems. Overhangs are designed to admit the low winter sun but block direct sunlight in summer. Indirect sunlight can be controlled with operable shading devices.*

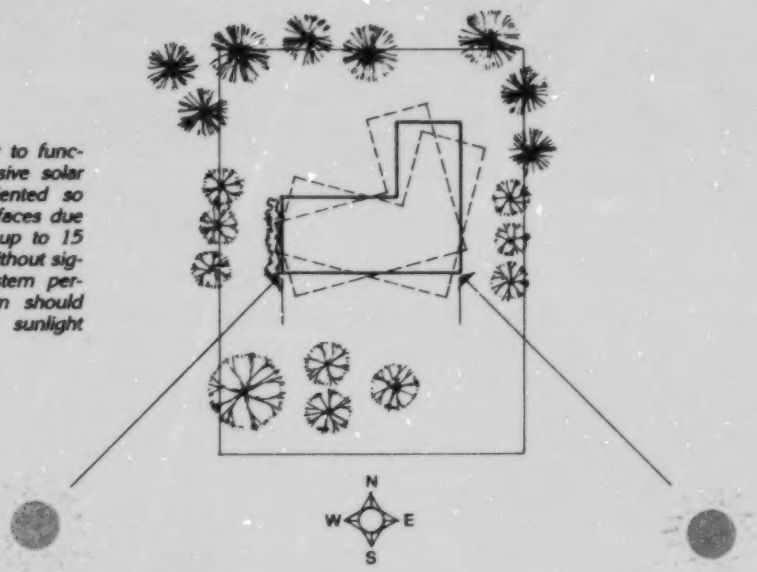
Site Planning

To achieve optimum performance from a passive solar home, it must be properly oriented with respect to south, so the building site should be selected carefully. The topography of the site as well as the natural landscape and vegetation will affect how the home performs and how much energy it consumes for heating and cooling.

A passive solar home must be oriented on its lot so that sunlight strikes its south face from 9 A.M. to 3 P.M. in the winter. The passive system, be it windows, a sunspace, or a mass wall, must be positioned to face within 15 degrees of true south. Variations of more than 15 degrees will diminish the system's heating performance and will increase unwanted heat gain from the east and west during summer.

Ensuring the correct orientation of the passive house is the first step in site planning. But there are other considerations in selecting a site that can enhance a solar home's performance. Natural site features – trees, topography, neighboring buildings – can influence how much energy a home consumes for heating and cooling. Knowing how these features affect energy consumption can help the home builder select a site that will reduce energy costs. What features to look for depends on whether heating or cooling consumes more energy dollars.

In some areas, the costs of heating and cooling are roughly equivalent. In other areas, one may be more costly than another depending on fuel source and the relative severity of the winter and summer seasons. In planning the site of a passive home, it is important to keep in mind which entails the larger expense – heating or cooling – and to take advantage of natural features that will reduce that particular energy demand.



Orientation: *In order to function effectively, a passive solar house should be oriented so that the solar system faces due south. This can vary up to 15 degrees east or west without significantly affecting system performance. The system should receive unobstructed sunlight from 9 A.M. to 3 P.M.*

Winter Heating

In areas where winter heating is the largest energy expense, an effort should be made to select a site that offers good exposure to the sun and, at the same time, protection from winter winds. Trees and shrubs can buffer winter winds, so in developing a lot, these should be preserved as much as possible on the east, west, and north sides. However, they may need to be removed from the south side if they block the low winter sun, because this will impair performance of the passive solar heating system. Deciduous trees are an exception, because they lose their leaves in winter allowing sunlight to get through. However, even deciduous trees can be a problem if their branches are so dense that they produce significant shade even when bare.

Sometimes the slope of the land can be used to advantage. For instance, if the site is such that the north wall of the house can be located close to a sheltering hill, this can provide protection from winter winds. Some designers go so far as to build a house partially into the side of a hill to take advantage of the earth's sheltering effect.

A clear sun path to the building's south wall is extremely important for winter solar heating. In selecting a site, it is necessary to consider nearby buildings, hills, trees, or other objects that are potential obstructions to the low winter sun. In evaluating the area surrounding a site, it is important to anticipate future construction as well as tree growth that might block the sunlight in later years. In some communities, owners of homes with solar systems obtain solar access easements from neighboring landowners to prevent construction or landscaping that will shade their solar system.

Summer Cooling

Summer cooling is a major expense throughout most of the South, and careful site selection can substantially reduce a home's air conditioning costs. Here, the most important site feature to look

Winter heating: *Deciduous trees shed their leaves in autumn, and their bare branches allow the winter sun to penetrate to the solar system. Evergreen trees on the north side buffer cold winter winds.*

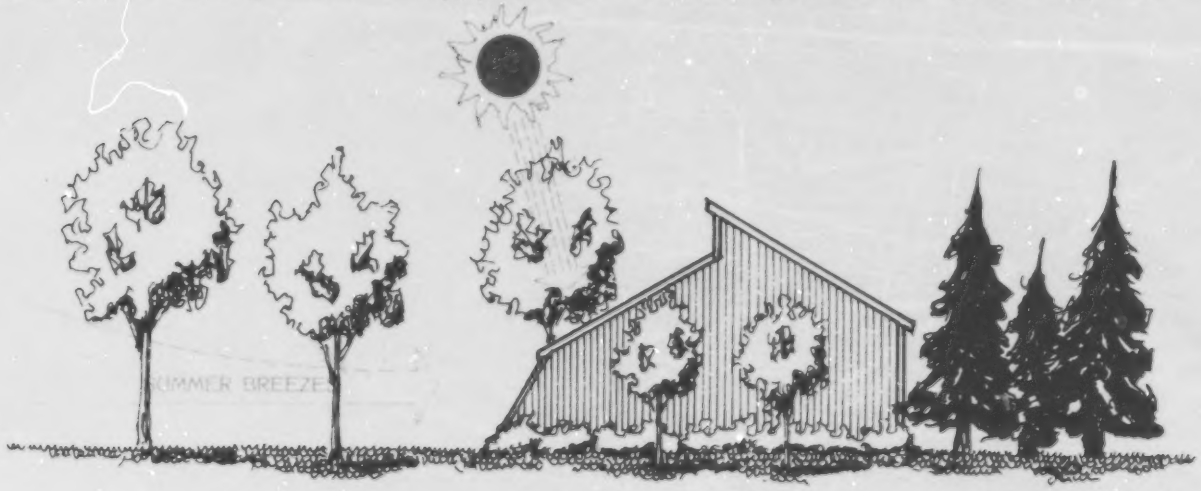
for is shade. Every effort should be made to preserve existing trees and vegetation that can shade the house and the ground around it. Air temperature in the shade of a tree can be 20 degrees cooler than in the sun, and the temperature of a shaded wall or roof can be 50 degrees cooler than an unshaded one. Thus, shading reduces the temperature around a house and, as a result, the temperature inside the house.

If a site is located in an area with prevailing summer breezes, consideration can be given to orienting the house to take advantage of them as a source of cooling. However, planning a site around the wind is not always practical, and even in areas with reliable prevailing winds, heat and humidity can render them ineffective for cooling.

It is always more efficient to preserve existing trees and shrubs on a site than it is to remove and replace them. However, landscaping can supplement what already exists and is an effective tool for increasing the comfort and the performance of a home. The same guidelines that apply to site selection apply to landscaping: deciduous trees for the south side of the house and evergreens for shade and windbreaks on the north, east, and west sides.

A few other landscaping points merit consideration. Paved areas near the house, such as patios and driveways, should be shaded because they absorb a lot of heat. Also, shading windows and other inlets to the house lowers the temperature of incoming air.

Not every site possesses features that can be used to complement both winter heating and summer cooling. Sometimes a feature that reduces winter heating bills, such as a clear southern exposure, can increase summer cooling costs. The reverse may also be true. For instance, a heavily shaded site can reduce cooling requirements, but winter solar heating may be impaired. Thus, the best site plan uses natural features to strike a balance between winter and summer energy requirements, with the emphasis placed on the season that generates the highest energy costs.



Summer cooling: *Deciduous trees in full leaf shade the passive system. They also cool breezes passing through their shade. Evergreen trees shade the north side in summer and act as wind breaks in winter.*

Solar House Plans

The following passive solar house plans have been specifically adapted to the heating and cooling requirements of this state. They represent a range of sizes and architectural styles. Each design is accompanied by a floor plan, section, and drawing of the house as well as a description of the home's passive solar features and projected energy consumption.

General Specifications

Reducing the home's energy load through standard energy conservation practices is the first step toward effective solar design. Thus, the passive solar plans contained in this book are energy efficient as well as energy producing. The accompanying table describes energy conservation features common to these passive solar plans and compares them to energy conservation features typical of most new houses. It should be noted that the plans are a result of an integrated design procedure by which the solar systems are matched to energy conservation features, overall house plan, and location of the house. Therefore, it is important not to make changes that might downgrade the insulation or other conservation features of the passive designs.

Projected Energy Consumption

Included in the description of each solar house is a summary of its projected heating and cooling energy use. These figures should be viewed as a relative measure of the home's performance in much the same way as miles-per-gallon figures are used for new cars. Just as driving patterns affect automobile gasoline mileage, occupant lifestyle determines the actual amount of energy consumed for heating and cooling.

Energy Conservation Specifications: Standard House vs Solar House

Feature	Standard House	Passive Solar House
1. Insulation		
Slab floors	None	R-5 or R-10
Frame floors	R-11	R-19
Walls	R-14	R-19
Ceilings	R-19	R-30*
2. Windows	Single glazing	Double glazing (R-2.2 or above)
3. Infiltration	Standard weatherization	Standard weatherization, plus vapor barrier on exterior walls, sill and sole plate sealants, and joint sealant for frame and masonry elements
4. Doors	Approx. R-3	R-12
5. Roof	Venting at soffit, ridge, and gable	Venting at soffit, ridge, and gable

*R-38 in areas exceeding 4,000 heating degree days

The performance table that accompanies each house plan contains four energy performance figures for the house calculated for Fayetteville, Fort Smith, Little Rock, and Texarkana: (1) total annual heating load (amount of energy, measured in million Btus, required to heat the house to 68°F); (2) heating savings, a measure of how much of a savings the total annual heating load represents in comparison to the standard house; (3) the solar savings fraction (expressed as a percentage), a measure of the portion of the home's heating requirements that are expected to be met by the solar system; and (4) total annual cooling load (energy required to cool the house to 78°F), expressed in million Btus.

Heating and cooling energy requirements of the solar houses, as well as estimated savings, are stated in terms of millions of Btus. These figures are given for purposes of comparison, and no attempt has been made to convert Btus into dollars. Instead, the energy consumption of the solar house is compared to the estimated energy use of a "standard" house of equal usable floor area without passive solar features. A description of the general energy features of the standard house is presented in the energy conservation specifications table. As the table shows, the standard house is a well insulated house even by today's standards. Because the standard house is so energy efficient, this comparison can be regarded as a fair reflection of energy savings attributable to all of the advanced energy features in the passive solar homes.

Projected energy savings and solar performance data have been included with the house plans for cities for which enough climate and solar radiation data existed to permit computer analysis. For cities not included, data for cities with similar climates can be used. If the house is to be built in a climate that differs substantially from that of the cities listed, an architect experienced in passive design should be consulted.

The solar savings of each house are stated in the table as a solar savings fraction. Though the solar savings fraction is a complex mathematical measure of solar performance, it can be simply described as a measure of the portion of a building's heating requirements that are met by the passive solar system.

Energy performance was calculated using a version of FCHART/SLR, a computerized solar design tool originated by the Northeast Solar Energy Center. The special version used here was adapted by the Southern Solar Energy Center to address the unique requirements of hot, humid climates.

Working Drawings

Working drawings may be obtained for each of the passive solar house plans contained in this collection. Each set of working drawings includes general notes and specifications and is accompanied by a booklet of general specifications covering construction items related primarily to passive solar elements and energy conservation features.

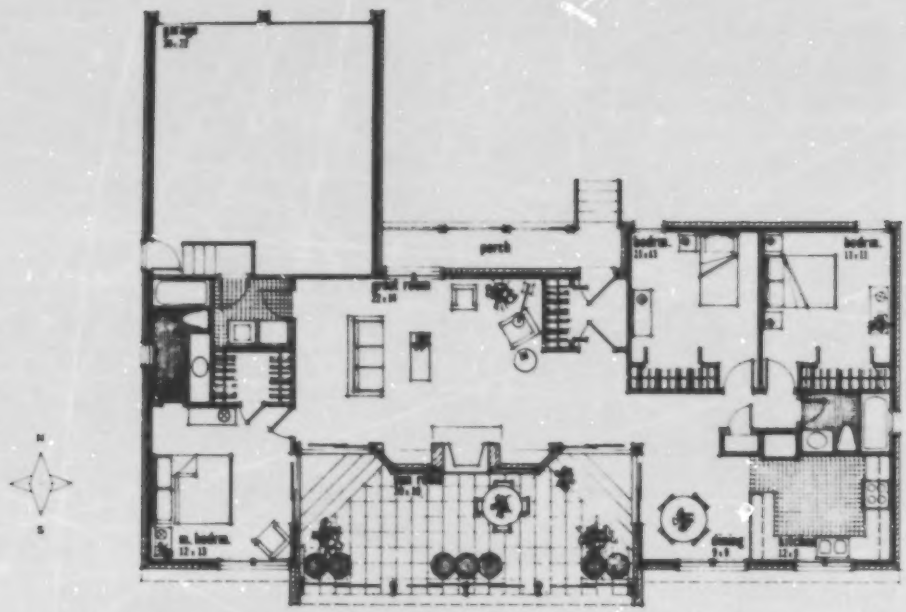
For information on ordering working drawings, contact:

Arkansas Energy Office
One State Capitol Mall
Little Rock, Arkansas 72201
(501) 371-1370

SOUTH VIEW

TRENT

From a design by Ralph McCay, Jr.
Charleston, South Carolina



Trent

Finished floor area: 1,470 square feet

Levels: 1

Bedrooms: 3

Baths: 2

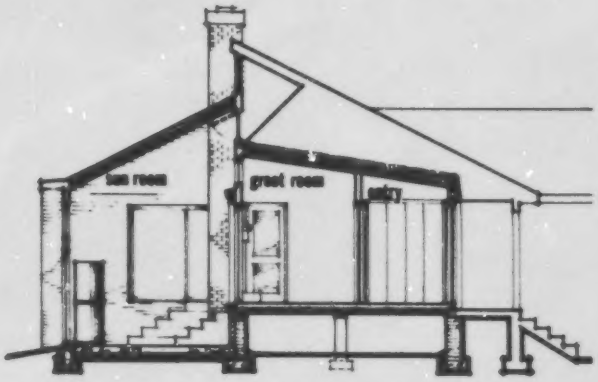
Passive solar features: Sunspace, direct gain windows

Thermal storage mass: Masonry floors and water drums

Sun control: Overhangs

Additional energy features:

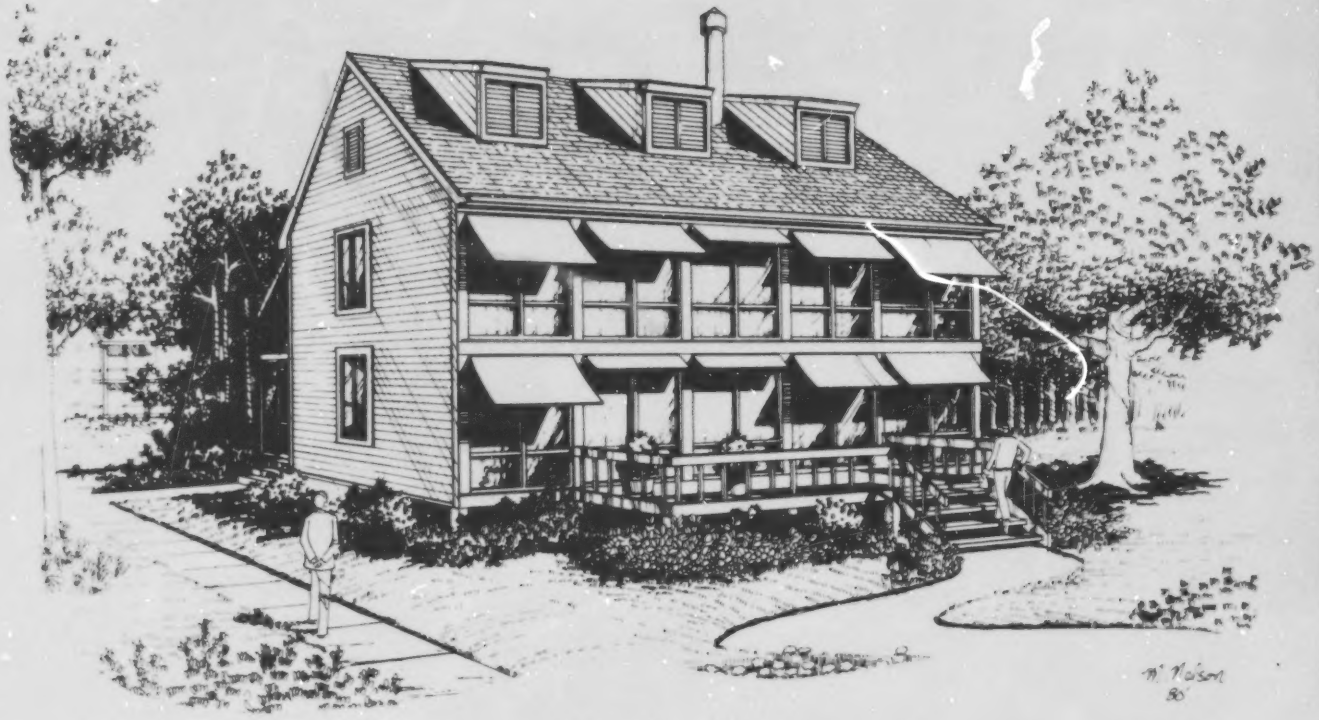
- Airlock entrance
- Heat recirculating fireplace
- Garage located on north side to buffer winter winds
- Window and door positioned to enhance cross ventilation
- Roof louvers to allow convective air venting in summer
- Thermostat-controlled fan in sunspace for summer venting



SECTION

PROJECTED ANNUAL ENERGY PERFORMANCE

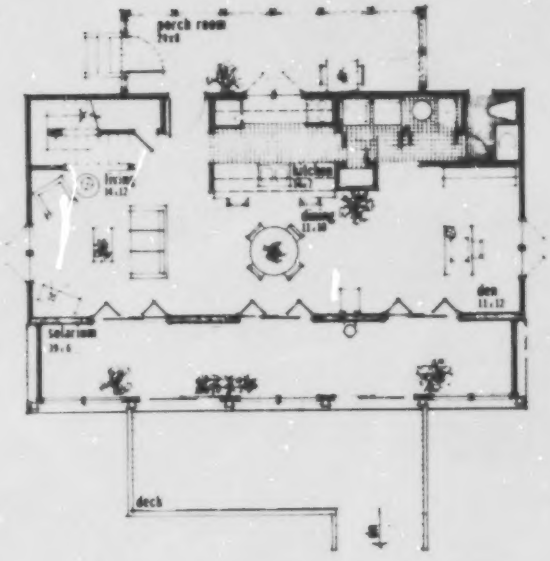
CITY	ANNUAL HEATING LOAD (MMBTU)	HEATING SAVINGS %	SOLAR SAVINGS %	ANNUAL COOLING LOAD (MMBTU)
Fayetteville	17.8	53	31	17.0
Fort Smith	14.5	56	36	19.9
Little Rock	14.5	56	35	19.4
Texarkana	8.6	64	48	21.5



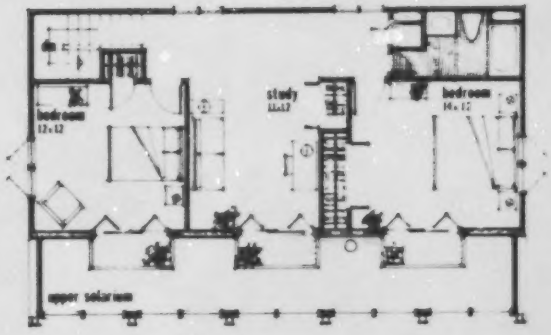
SOUTH VIEW

BURLEIGH

From a design by: Dennis Donahue and Stacy Hull
Charleston, South Carolina



FIRST LEVEL



SECOND LEVEL

Burleigh

Finished floor area: 1,600 square feet

Levels: 2

Bedrooms: 2

Baths: 1½

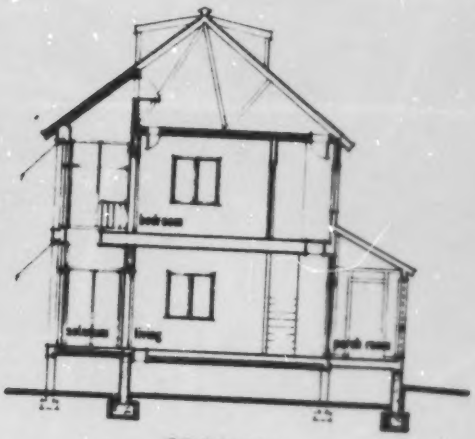
Passive solar features: Sunspace

Thermal storage mass: Masonry wall

Sun control: Operable shading awnings, insulated interior shutters at sunspace doors

Additional energy features:

- Airlock entrance
- Thermostat-controlled fan to vent sunspace
- Minimal east and west glazing to reduce winter heat loss and summer heat gain
- Dormer vents for venting of sunspace and attic
- High ceilings to enhance natural ventilation



SECTION

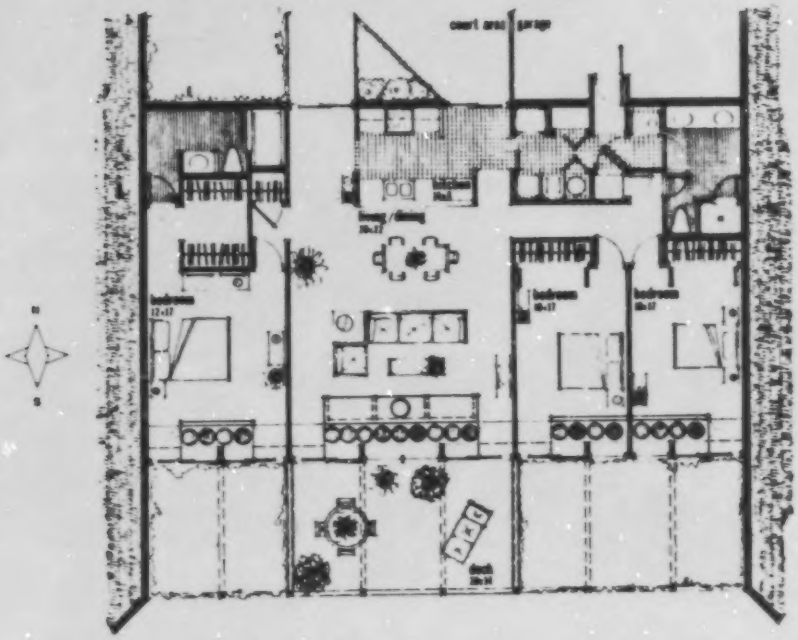
PROJECTED ANNUAL ENERGY PERFORMANCE

CITY	ANNUAL HEATING LOAD (MMBTU)	HEATING SAVINGS %	SOLAR SAVINGS %	ANNUAL COOLING LOAD (MMBTU)
Fayetteville	14.4	73	44	17.1
Fort Smith	11.3	76	50	17.9
Little Rock	11.3	76	49	18.4
Texarkana	5.9	83	64	20.6

SOUTH VIEW

ASHTON

From a design by: James Knight and Bob Heatly
Stillwater, Oklahoma



Ashton

Finished floor area: 1,782 square feet

Levels: 1

Bedrooms: 3

Baths: 2

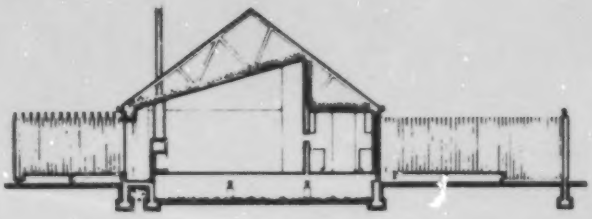
Passive solar features: Water wall

Thermal storage mass: Water drums and masonry floors

Sun control: Operable trellises

Additional energy features:

- Wind walls to funnel prevailing summer winds
- Heat-recirculating fireplace
- Walled courtyard and garage on north side to buffer winter winds
- Daytime living spaces located on south side to take advantage of heat and light
- Air distribution system to circulate solar-heated warm air to interior of house
- Earth berms on east and west sides to buffer winter winds and summer heat

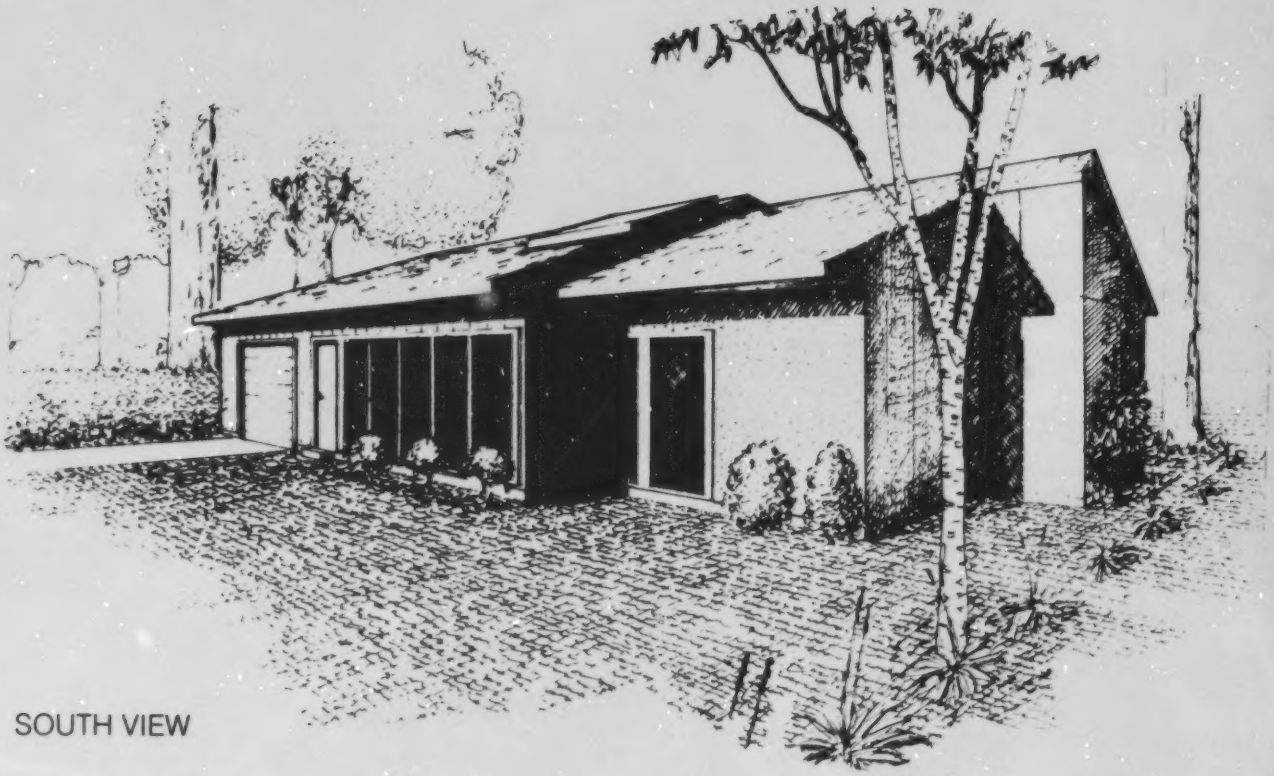


SECTION

PROJECTED ANNUAL ENERGY PERFORMANCE

CITY	ANNUAL HEATING LOAD (MMBTU)	HEATING SAVINGS %	SOLAR SAVINGS %	ANNUAL COOLING LOAD (MMBTU)
Fayetteville	34.0 (26.9)*	25 (40)	24 (25)	21.4 (18.5)
Fort Smith	28.5 (22.5)	27 (43)	27 (28)	25.2 (21.2)
Little Rock	28.3 (22.4)	27 (42)	27 (28)	24.8 (20.9)
Texarkana	18.6 (14.6)	34 (48)	36 (37)	27.6 (23.4)

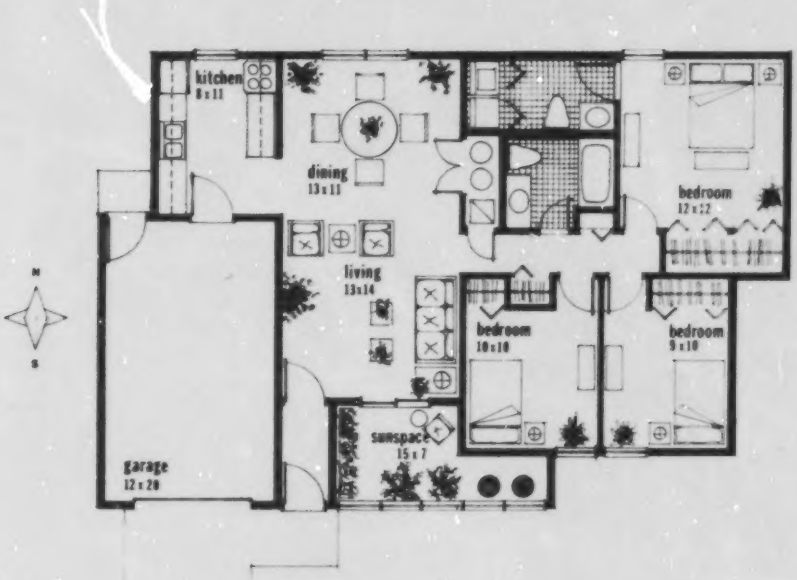
*Figures in parentheses are for an alternate version with improved energy performance, but reduced window area. This version is included with the working drawings.



SOUTH VIEW

BARCLAY

From a design by McCune, McCune Associates
Tulsa, Oklahoma



Barclay

Finished floor area: 1,213 square feet

Levels: 1

Bedrooms: 3

Baths: 2

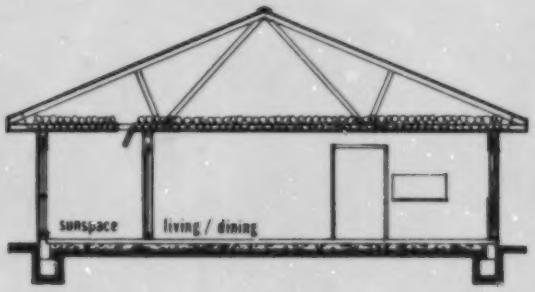
Passive solar features: Sunspace, direct gain windows

Thermal storage mass: Water tubes, masonry floors

Sun control: Overhangs

Additional energy features:

- Airlock entrance
- System to distribute solar heated air from sunspace to interior of house



SECTION

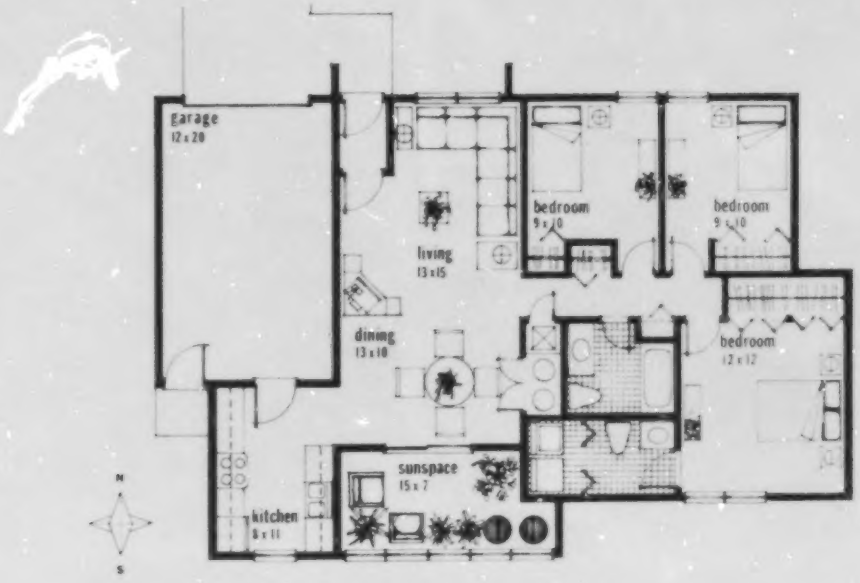
PROJECTED ANNUAL ENERGY PERFORMANCE

CITY	ANNUAL HEATING LOAD (MMBTU)	HEATING SAVINGS %	SOLAR SAVINGS %	ANNUAL COOLING LOAD (MMBTU)
Fayetteville	10.2	67	38	13.1
Fort Smith	8.1	70	43	14.3
Little Rock	8.1	69	42	14.4
Texarkana	4.5	77	56	16.1

SOUTH VIEW

CHADWICK

From a design by McCune, McCune Associates
Tulsa, Oklahoma



Chadwick

Finished floor area: 1,223 square feet

Levels: 1

Bedrooms: 3

Baths: 1½

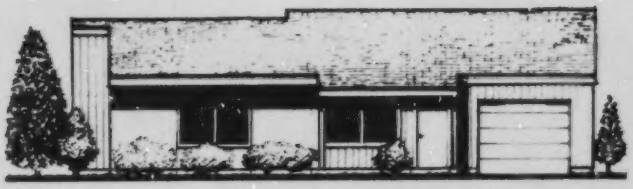
Passive solar features: Sunspace, direct gain windows

Thermal storage mass: Water tubes, masonry floors

Sun control: Overhangs

Additional energy features:

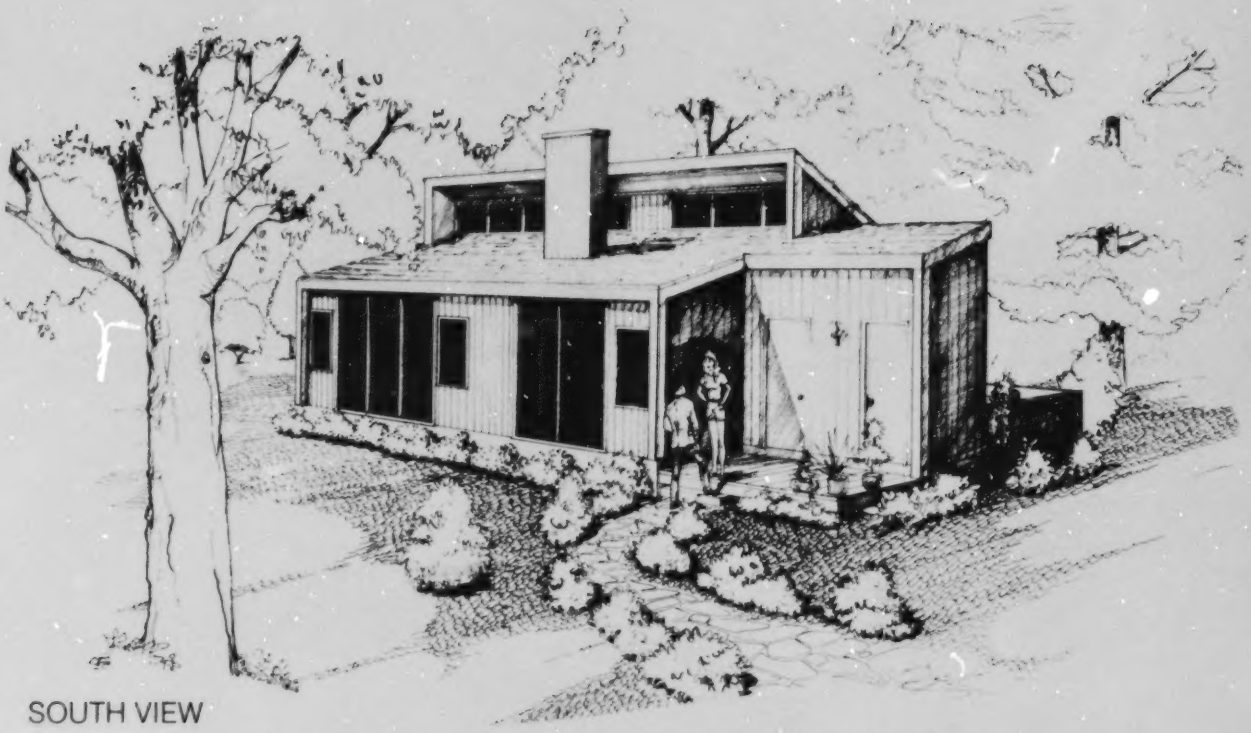
- Airlock entrance
- Air distribution system to circulate heated air from sunspace to interior



NORTH VIEW

PROJECTED ANNUAL ENERGY PERFORMANCE

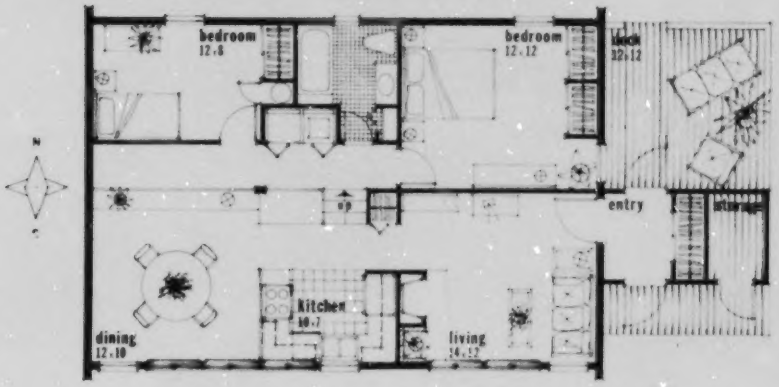
CITY	ANNUAL HEATING LOAD (MMBTU)	HEATING SAVINGS %	SOLAR SAVINGS %	ANNUAL COOLING LOAD (MMBTU)
Fayetteville	8.4	73	41	11.3
Fort Smith	6.6	75	46	12.5
Little Rock	6.6	75	45	12.7
Texarkana	3.5	82	59	14.2



SOUTH VIEW

HAWTHORNE

From a design by: One Design, Incorporated
Winchester, Virginia



Hawthorne

Finished floor area: 1,008 square feet

Levels: 1

Bedrooms: 2

Baths: 1

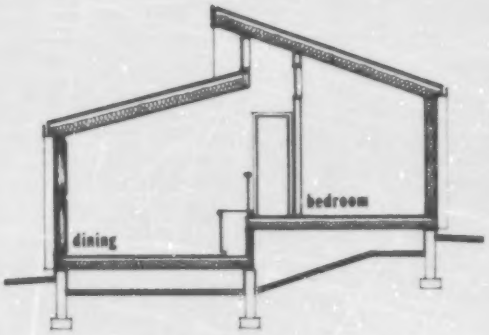
Passive solar features: Water walls, clerestory windows for direct solar gain

Thermal storage mass: Water containers

Sun control: Overhangs

Additional energy features:

- Wood stove with central masonry wall to store its heat
- Omission of east and west glazing to reduce winter heat loss and summer heat gain
- Airlock entrance
- Clerestory design for direct-gain solar heating, natural lighting, and ventilation



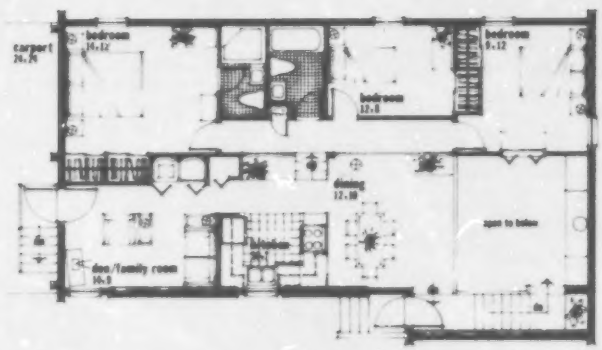
SECTION

PROJECTED ANNUAL ENERGY PERFORMANCE				
CITY	ANNUAL HEATING LOAD (MMBTU)	HEATING SAVINGS %	SOLAR SAVINGS %	ANNUAL COOLING LOAD (MMBTU)
Fayetteville	5.7	77	48	14.3
Fort Smith	4.3	77	54	16.8
Little Rock	4.4	77	52	16.7
Texarkana	2.0	86	68	18.7

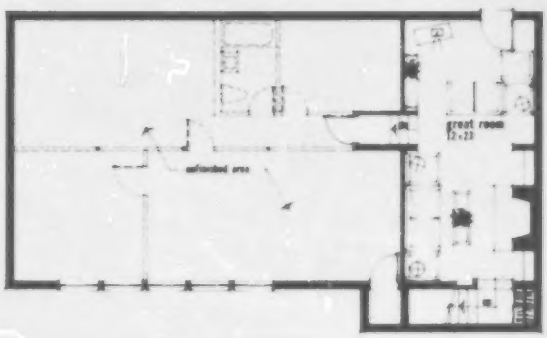
SOUTH VIEW

INDEPENDENCE

From a design by: One Design, Incorporated
Winchester, Virginia



FIRST LEVEL



LOWER LEVEL

Independence

Finished floor area: 1,220 square feet

Levels: 2

Bedrooms: 3

Baths: 2

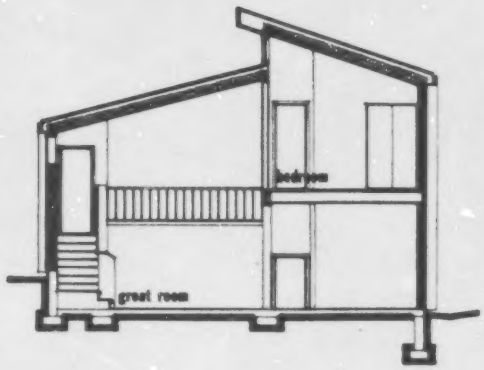
Passive solar features: Water wall, direct-gain windows

Thermal storage mass: Containers of water

Sun control: Overhangs

Additional energy features:

- Wood stove with central masonry wall to store its heat
- Daytime living areas located on the south side for solar heat and natural light
- Minimal east and west glazing
- Clerestory design for direct-gain solar heating, natural lighting, and ventilation



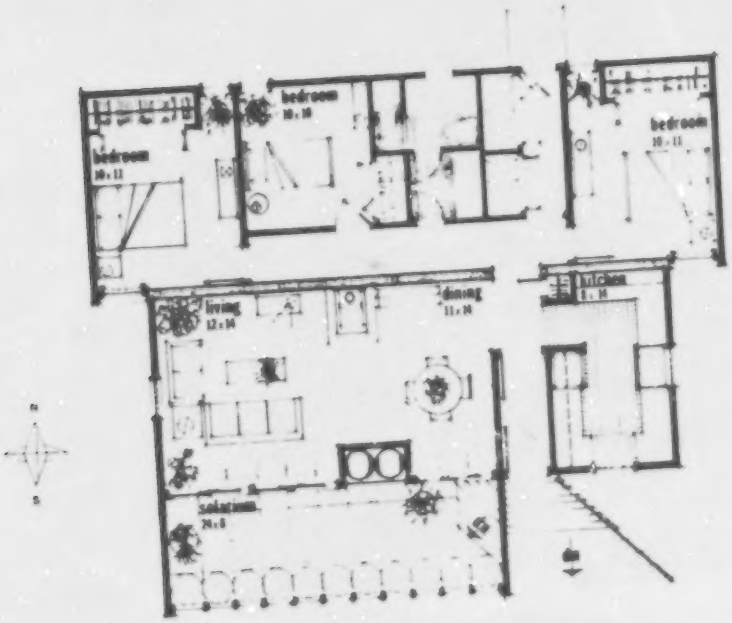
SECTION

PROJECTED ANNUAL ENERGY PERFORMANCE				
CITY	ANNUAL HEATING LOAD (MMBTU)	HEATING SAVINGS %	SOLAR SAVINGS %	ANNUAL COOLING LOAD (MMBTU)
Fayetteville	14.1	54	48	18.0
Fort Smith	11.1	59	53	21.9
Little Rock	11.2	58	52	21.5
Texarkana	6.0	69	65	24.1

SOUTH VIEW

LARGO

From a design by Richard Seedorf
Atlanta, Georgia



Largo

Finished floor area: 1,188 square feet

Levels: 1

Bedrooms: 3

Baths: 1

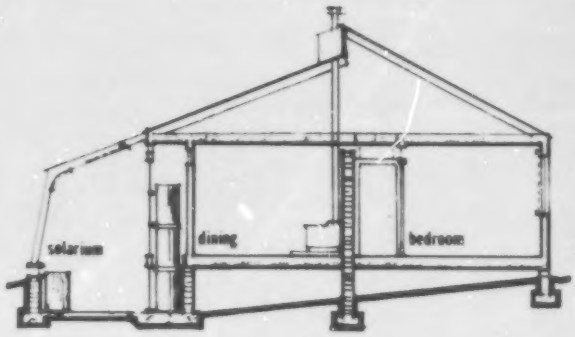
Passive solar features: Sunspace

Thermal storage mass: Concrete floors and water drums

Sun control: Adjustable shading device for sunspace

Additional energy features:

- Daytime living areas grouped on south side to take advantage of solar heat and natural lighting
- Airlock entrance
- Wood stove with central masonry wall to store its heat
- Whole house fan for venting attic and living space
- Minimal east and west glazing to reduce winter heat loss and summer heat gain
- Thermostat-controlled fan to vent sunspace in summer



SECTION

PROJECTED ANNUAL ENERGY PERFORMANCE

CITY	ANNUAL HEATING LOAD (MMBTU)	HEATING SAVINGS %	SOLAR SAVINGS %	ANNUAL COOLING LOAD (MMBTU)
Fayetteville	13.1	57	38	19.3
Fort Smith	10.4	61	44	21.2
Little Rock	10.9	60	43	21.5
Texarkana	5.4	71	59	24.1

Working drawings for *Solar Homes for Arkansas* may be obtained by contacting:

Mr. Tom Brown
Capital Blueprint and Supply Company, Inc.
1301 West Capitol Street
Little Rock, Arkansas 72201
(501) 376-2446

Trent - $12.85

Burleigh - $10.00

Ashton - $12.00

Barclay - $10.00

Chadwick - $10.00

Hawthorne - $7.50

Independence - $10.00

Largo - $8.75

Disclaimer

This plan book was prepared by the Southern Solar Energy Center for the Arkansas Energy Office as an account of work sponsored by the United States Government to encourage the development of solar housing.

The designs, drawings, and specifications available through this plan book are suitable for construction in the state of Arkansas. Since each design will have to be modified somewhat to suit the specific conditions of the chosen site, a professional familiar with solar design in Arkansas should be consulted before beginning construction. Factors such as slope, drainage, soil-bearing capacity, and solar orientation must be considered carefully for the home to perform as designed. In addition, the working drawings and specifications should be reviewed with local building officials for compliance with code requirements prior to site selection, financial commitment, or construction permit applications.

Neither the Southern Solar Energy Center, the Arkansas Energy Office, the United States, or any agency thereof, or any of their employees make any warranty, expressed or implied, or assumes any legal liability or responsibility for any use or the results of such use of any information, apparatus, or assembly, product, or functional efficiency exhibited within this plan book or represents that their use would not infringe upon privately owned designs and rights.

SOLAR ENERGY BIBLIOGRAPHY

The following publications are available through the Arkansas Energy Office free of charge to Arkansans. Single copies may be obtained by writing the Energy Office or calling the Statewide Hotline (1-800-482-1122).

SOLAR ENERGY. A general guide to solar energy in Arkansas; appendices; bibliography, 1981. 71 pp.

SOLAR HOT WATER. Plans for several types of solar water heaters. 1981. 80 pp.

SOLAR GREENHOUSES. Plans for construction of a solar greenhouse to help reduce utility bills and grow plants at the same time; appendices; bibliography. 1980. 38 pp.

ARKANSAS SOLAR RETROFIT GUIDE.* Explains low-cost and cost-effective solar projects which can be added to your existing home; appendices. 1981. 102 pp.

ARKANSAS CLIMATE ATLAS.* Provides detailed climatological data for design professionals; appendices; bibliography. 1981. 94 pp.

*Contains annual and monthly solar radiation values for the State of Arkansas.

Arkansas Energy Future

Solar Greenhouses

ACKNOWLEDGMENT

The funding for this research was provided by a grant from the Ozarks Regional Commission.

The author wishes to thank Bill Brown, Bob Bland, Mary Jo Rose, Joe Henry, and Margo Clark for their valuable contributions regarding the design and construction of low-cost solar greenhouses.

The statements, findings, conclusions, recommendations, and other information in this book are solely those of the author and do not necessarily reflect the views of the Ozarks Regional Commission, the Federal and State Members of the Commission, the Commission's Energy Advisory Panel, nor the United States Department of Energy.

The J.D. Trahan greenhouse in Madison County demonstrates that greenhouses may be built of simple materials, yet add to the beauty of a house. This project was the joint work of the Office of Human Concern of Rogers and the Ozarks Institute of Eureka Springs.

INTRODUCTION

The word greenhouse usually brings to mind the long glass structures used by wholesale florists and commercial vegetable growers. Their design was developed when fuel was cheap, so no effort was made to use the sun's energy to reduce heating costs.

Since fuel costs have risen so drastically in recent years, a new residential greenhouse concept has emerged that effectively uses solar energy as the only heat source. By attaching these solar greenhouses onto homes, families throughout Arkansas can enjoy free supplemental heat in winter and year-round fresh vegetables at a very low cost.

Solar greenhouses are the most simple and economic of all solar applications. Unlike some other solar devices, greenhouse construction does not require complex equipment or technical skills. Using common materials bought locally at a building supply store, an 8 foot x 16 foot (112 square feet) unit can be owner-built for $300 to $800; the cost is approximately double that price range for an installed greenhouse. Of course, the cost would be much less if recycled materials were to be used.

As heating costs for your home continue to climb, a solar greenhouse becomes more valuable. This point was proven by the Ozarks Institute of Eureka Springs and the Office of Human Concern in Rogers, in a project in which several solar greenhouses in Arkansas were monitored during the winter of 1978-79.

Although that winter was one of the coldest and cloudiest on record, results showed that a 15-20 percent savings in heating costs could be expected for a typical 1500-square-foot

home, and the greenhouse could pay for itself in only three to five years.

For the thousands of Arkansas families who already grow their own food, a solar greenhouse can be used with the garden to increase the yearly food production. Seedlings can be started in the greenhouse to lengthen the growing season in spring and fall, or they can be sold to neighbors for additional income.

The Rhonda Dixon greenhouse in Benton County provides a relaxing atmosphere for a soaking tub.

Fresh vegetables are an important element to good heaith, but such produce is almos. impossible to obtain for more than half the year. The solar greenhouse can provide these vitamin-filled foods through the winter, when they are most needed.

An attached solar greenhouse also offers a warm, bright living space which can be used as an entry, a playroom, a breakfast nook, or recreation area. Persons who are elderly or handicapped and cannot manage the physical labor of gardening can enjoy working in the lively atmosphere of the "sunspace" during the cold winter months.

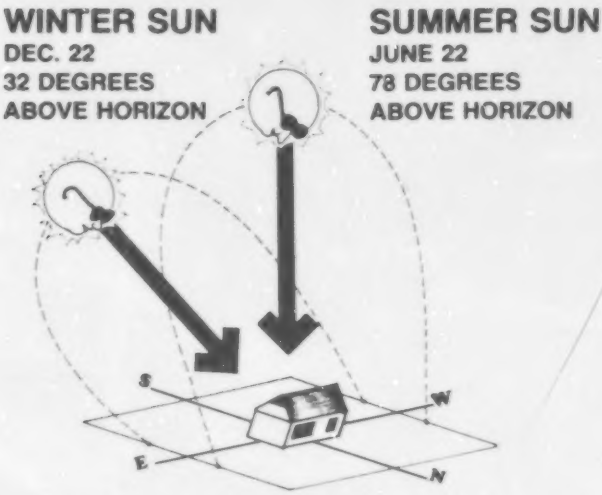
An attached solar room, whether it is used to grow plants or not, adds resale value to the home that exceeds the cost of the addition.

Residences are not the only places to consider solar greenhouses. Schools of all grade levels could benefit by including solar greenhouses as part of their educational programs. Students could get direct working experience with a practical solar application as well as with plant science and agriculture. In addition, school officials would enjoy reduced heating costs in the building.

Solar greenhouses on community centers, mental retardation facilities, and nursing homes could offer many educational and recreational opportunities. They can also serve as an effective way to raise our awareness of energy conservation in general and practice solar applications in particular.

HOW THEY WORK

Perhaps you have noticed how a car gets hot inside when it is parked in the sun, even on a cold day. A solar greenhouse, or sunspace, acts in a similar way. However, it not only collects solar heat in winter, it also distributes some of this heat to the house and stores some heat for use at night.



The sun takes a different position in the sky as the seasons change, and greenhouses take advantage of this movement.

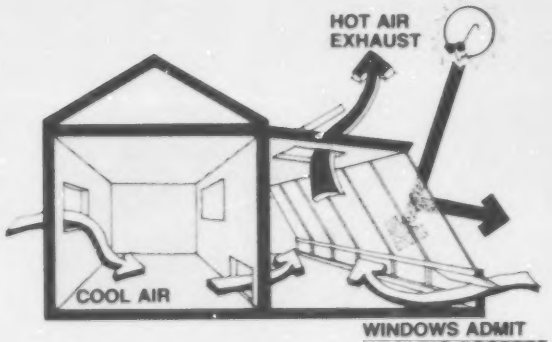
By orienting the greenhouse to take advantage of natural climatic forces, it can be heated entirely by solar energy. Proper design of thermal storage and ventilation will ensure adequate light and temperature levels for year-round plant growth.

In winter, the solar greenhouse traps as much solar energy as possible. Some of this heat is absorbed by heavy materials placed within the space, such as containers of water, rocks, or earth. This thermal storage is heated during the day, and slowly releases that heat to the greenhouse at night.

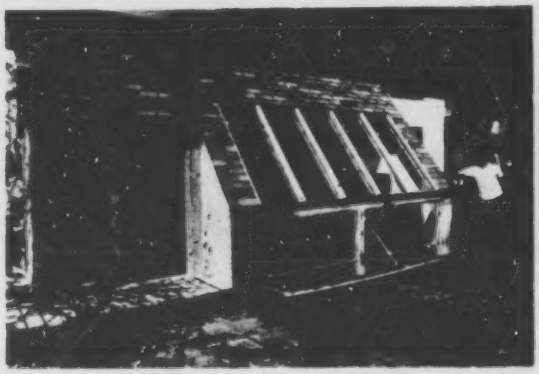
During sunny winter days, a substantial quantity of excess heat is distributed by natural air convection or a fan through openings to the house. The greenhouse also serves as a buffer zone to reduce heat loss from the house to the outdoors.

In summer, outside vents are opened and shading devices are used to keep the space cool. In spring and fall, a balance of these controls is often necessary to maintain even temperatures.

In winter, air heated by the sun flows into the house along the ceiling; at the same time, cooler air is drawn from the house into the greenhouse, along the floor. A fan may be used to increase the efficiency of the system.



In summer, vents exhaust overheated air from a greenhouse, and low-level windows admit cooling breezes.



Shutters reflect winter sunlight into the greenhouse owned by John and Coleen Standquist in Carroll County, and at night, the shutters are closed to cut loss of heat.

DESIGNING THE GREENHOUSE

Solar greenhouse designing is a particular challenge in Arkansas because weather conditions can be extreme and unpredictable in both summer and winter. It is not uncommon for the average solar radiation to vary by 30 percent, or the growing season to change by 50 days from one year to the next, especially in mountainous regions.

Also, the particular climate of your building site called the micro-climate, will be influenced by the type and location of trees and foliage, bodies of water, adjacent buildings, slope of the land, and by whether the site is in a mountainous, hilly or flat region.

Weather information for your specific area may be obtained from the National Weather Service at Little Rock. The bureau will answer questions on the average temperature, precipitation, and humidity in your area. Write the Weather Service at 8400 Remount Road, North Little Rock, Arkansas, 72118.

Since there are so many factors that determine heat loss and heat gain, thermal performance varies greatly from one design to another. There is no one way to build a solar greenhouse; rather, each one should reflect the particular needs and resources of the owner.

The criteria for design should be based on how the space will be used, what kind of plants (if any) will be grown, what materials are locally available, and how the greenhouse can be adapted to the existing building for easy access and heat distribution. Follow the design requirements for venting, glazing, and heat storage as given in this text and be prepared to adjust these elements to suit your heating and gardening needs.

Since the sun rises in the southeast and sets in the southwest during the winter months, a greenhouse on the south side of a structure will receive the most solar energy available at that time of year. The southern wall of the house is the ideal location, but shading, space, or access problems may indicate a southeast or southwest location instead. The winter performance will be nearly equal for any orientation within 30 degrees of south.

More important than a true south direction is a convenient access to the greenhouse from the house. By building the greenhouse over existing windows or a door, venting warm air to the home will be simple.

If no doors are present, it will not be difficult to make one over an existing window. Think how nice it would be to enter the greenhouse right from your kitchen or living room!

Shade trees at the home of Sam and Helen Armstrong at Rogers reduce the ventilation area required in their greenhouse.

When you decide what kind of greenhouse is right for you and where it should be located, check with your local government about a **building permit.** Building inspectors may require a drawing of the project showing the location of the house and the addition, property lines, easements, and utilities.

TILTED COMPARED TO VERTICAL GLAZING

Glazing is glass, fiberglass, or other material that allows light to pass through. It covers the south face of a solar greenhouse and sometimes is used on the east and west walls. Although more heat will be lost at night through glazing on the east or west walls than will be gained from solar radiation, the longer period of direct light will benefit certain plants.

Frequently, the south face of glazing is tilted to about 60 degrees from the horizontal. This angle will maximize light and heat transmission during winter when the sun rises to about 30 degrees above the horizon. Thus, nearly all the direct solar radiation, which is the form of solar energy we receive on clear days, can pass straight through the glazing without being reflected. This will also be steep enough to prevent accumulations of snow and ice that might otherwise threaten to cave in the roof.

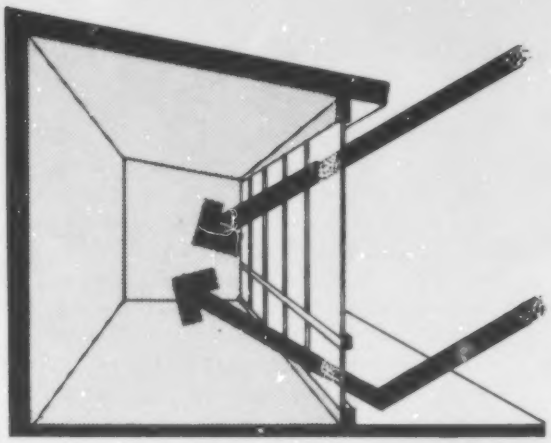
Tilted glazing also collects a large amount of diffuse radiation, which is the solar energy available on cloudy days. Depending on local cloud cover, diffuse radiation could represent up to 30 percent of the total solar heat available during the winter.

Since rain and snow will fall on tilted glazing, extra care must be taken to ensure a watertight seal at all exposed seams. Also, a means to shade the glazing during summer is necessary to keep the space from overheating.

Of all the factors that control summertime temperatures within the greenhouse, shading is the most critical. Shading methods include trees and vines that lose their leaves in the fall, canvas awnings, wooden or bamboo lattices, and shade cloths like those used on commercial greenhouses.

Glazing that is built vertically works as well if there is a light-colored area in front to reflect additional light into the greenhouse. This area

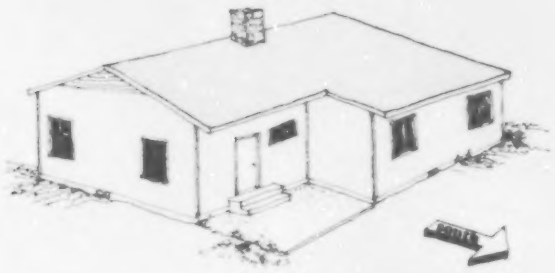
could be white-painted concrete or a wooden deck, or a specially designed reflector. This reflector may be hinged to the greenhouse and set at different angles during the year to maintain even light levels within the greenhouse. At night, it can be closed over the glazing to function as an insulating shutter.



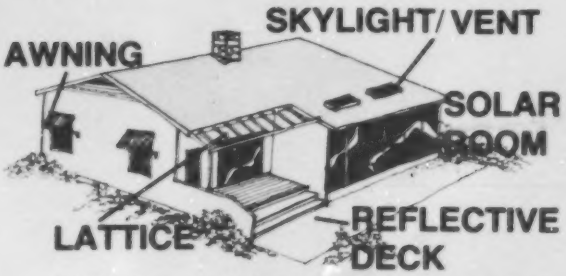
Light is directed into a greenhouse from a reflective deck on the ground outside.

A slight roof overhang will automatically shade vertical glazing during the summer when the sun is at its highest position. This feature eliminates the need for other shading devices that are required for tilted glazings.

Whether the glazing is tilted or vertical, it is important to reflect as much light as possible off the interior walls to achieve a light balance in the space. By building the greenhouse no more than 8 to 10 feet deep, the low winter sunlight can penetrate all the way to the house wall. The reflected light from the house wall balances the direct light from the glazing to simulate outdoor conditions, so that plants will grow evenly.



A sunspace that provides heat in winter may be obtained from a south-facing garage or room without great expense.



The sun heats this house through a bank of south windows, aided by the reflective deck in front, while excess heat is vented through skylights on the roof, awnings on the west windows, and the lattice over the entry.

TYPES OF GLAZING

The most important qualities for solar green house glazing are:

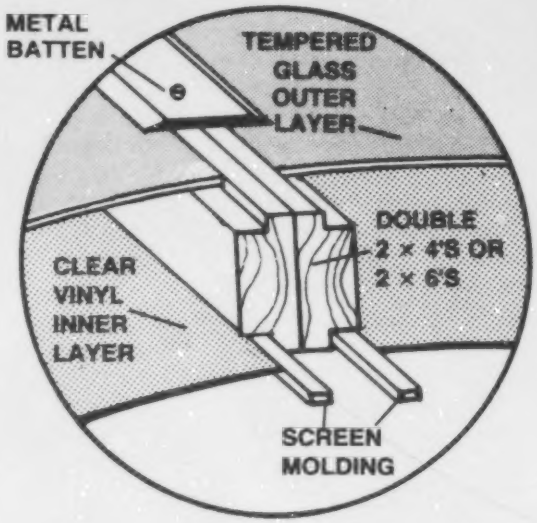
- resistance to degradation from heat, light and weather;
- good insulating property to protect against heat loss;
- high transmittance of solar radiation;
- local availability;
- ease of handling and fabrication; and
- low cost.

Glass is usually more expensive than other glazing materials, but when all factors are considered, it is often regarded as the best choice. Glass is rigid, clear, highly-durable, and resistant for many years to weathering.

Most local glass companies stock "replacement panels" that are tempered glass sheets used to make sliding glass doors. Their superior strength makes them ideal for tilted surfaces that must withstand severe thermal stresses, wind and snow loads, and impact from hail and other objects. Often, panels with slight imperfections can be bought at a very low price for wholesale glass distributors and salvage yards.

Unlike tempered glass, non-tempered window glass can be cut to custom sizes. Available in single or double strength with a very high solar transmittance of 0.91, its use should be limited to low-stress application such as vertical glazing.

Sources of glass that are often overlooked are auctions, yard sales, landfills, and demolition projects. Scrounging for old windows and storm doors can save you hundreds of dollars and produce a unique and attractive greenhouse. Take the time to investigate these sources in your area before buying any new glazing. Remember, used glass works just as well as new glass; it just costs a lot less.



Tempered glass on the outside and clear plastic on the inside create a snug greenhouse in winter.

Fiberglass is a common name for fiberglass-reinforced polyester (FRP) glazing, which has been used for many years as a patio and carport covering. In recent years, several manufacturers have formulated the fiberglass with chemicals to resist yellowing and deterioration from the ultraviolet rays of the sun. However, even these treated glazings need to be re-coated every few years with a special weathering agent to restore the original finish and resist decay.

Fiberglass is popular as a glazing for solar greenhouses and collectors because it is lightweight, impact-resistant, and easy to cut and install. Although it is cloudy enough to prevent a view to the outside, fiberglass will admit nearly as much solar radiation as glass. The cloudiness might be seen as an advantage in urban areas where privacy is a concern.

Fiberglass is usually available in 4-foot rolls or 26-inch wide corrugated panels in various lengths and thicknesses. The biggest complaint against the roll type is its appearance: it does not lie flat, resulting in a wavy pattern. Corrugated panels are much more rigid and give the feeling of a more permanent structure. Special redwood strips must be used along the supports of the panels for a tight seal to prevent air infiltration. Also, the enlarged surface area of the panels due to the corrugations will slightly increase the heat loss at night.

Three of the most-often-used fiberglass brands are Sears, Filon, and Kalwall. Sears fiberglass can be ordered through the company catalog, and Filon can be bought through many building supply stores in Arkansas. Since Filon makes two kinds of fiberglass, be sure to specify the "greenhouse" type that is more expensive, but lasts much longer than the untreated type. Kalwall's "Sun-

Clear plastic stretched on a frame provides a low-cost inner glazing in this greenhouse at the Siloam Springs Child Development Center.

lite" must be ordered from a solar supply catalog or directly from the manufacturer.

Rigid plastic glazings are attractive, easy to handle ad fabricate, and have high impact and fracture resistance.

Most of the plastic products can be categorized as either acrylics or polycarbonates. **Acrylics,** such as Plexiglas, Lucite and Acrylite, are known for their high solar transmittance and good resistance to ultraviolet light and weathering. **Polycarbonates** such as Lexan also have a very high impact strength, but will yellow in sunlight sooner than acrylics.

The major disadvantages of plastics as greenhouse glazings are their cost and poor resistance to scratching. Like fiberglass products, plastics are petroleum-derived, so their cost will continue to rise with the cost of oil.

Plants are spaced about the greenhouse for efficient use of the space.

Solar greenhouses in Arkansas will perform better if two layers of glazing are used. Although an extra layer of glazing will reduce the light transmission by 10 to 20 percent, it will also reduce heat loss at night by nearly 50 percent.

Double-glazed glass, fiberglass, or plastic panels that have been factory-sealed to prevent condensation are usually too costly for most greenhouses. So, double glazings are often assembled on the job, with the outer layer being glass or fiberglass to withstand the weather and an inner layer of polyethylene or vinyl film.

The lowest-cost inner glazing is polyethylene film. It is commonly used in the construction industry as a vapor barrier, so it is available at most building supply stores. Polyethylene comes in varying widths up to 12 feet and can be stapled to the bottom of glazing rafters in one continuous sheet. Useful life is limited to one or two years; however, considering the low cost of the material, replacing it every year is not a problem.

Some very successful greenhouse designs use polyethelene for both the inner and the outer layers of glazing. In summer, the film is entirely removed to transform the space into an outdoor garden or porch. In fall, new plastic is easily installed to create a solar room again.

Another type of inner glazing is clear, flexible plastic or vinyl film. These films are usually sold as storm-window glazing and are easily cut to any size. When stretched over wood or aluminum or screen-molding frames, they can be removed in summer and reused in winter for several years. By using the inner glazing just in winter, when it is needed, it will last much longer than when it is left on year round. These films are more expensive than polyethene, but are much stronger, so they can be handled from year to year without damage and, like glass, they offer a clear view to the outside.

MOVABLE INSULATION

Glazing is the largest heat loss problem of any greenhouse. Even well-sealed double glazing will lose heat at night about 12 times faster than an insulated wall. Movable insulation covers the glazing at night to drastically reduce heat loss and is removed during the day to permit solar heat gain.

Movable insulation that must cover large areas of glazing presents several design considerations. The most critical is the placement of the insulation during the day, when it is not covering the glazing. A second significant issue is the potential interference of plants with the movement of the insulation. A third consideration is obtaining a tight fit when the insulation is covering the glazing.

Types of movable insulation include rigid panels, folding shutters, and thermal curtains. These devices are usually homemade from common hardware and fabric matrials. However, they can add considerably to the cost and complexity of the greenhouse, and are required only if warm (50°F to 60°F) nighttime temperatures are needed.

The simplest form of movable insulation is rigid styrene, also called beadboard or Styrofoam, 1½ or 2 inches thick, placed against the glazing only on the coldest nights of the year. This lightweight material can be easily cut to fit between the glazing rafters for a tight seal. By attaching hinges to the styrene, it can be retracted against the ceiling during the day.

Thermal curtains can be made by quilting polyester insulation and a polyethelene vapor barrior between two layers of fabric. Curtains have the advantage of covering the entire glazing in one piece, thus eliminating heat losses that occur at the joints of insulation panels. Thermal curtains can use the same hardware as conventional curtains; for vertical glazing, they are usually pulled from side to side, while tilted glazings use curtains that roll to the ceiling.

An alternative to movable insulation is to open the door or windows from the house on very cold nights, allowing the house heat to help keep the greenhouse warm.

THERMAL STORAGE

Most of the sunlight that enters the greenhouse should fall either on the plants or on dark, heat-absorbing material, such as containers of water, masonry, or earth. These materials have a high thermal mass, which means they act like "heat sponges" to absorb heat, and later release it to the air, as the space cools down. The solar heat gains to the greenhouse are stretched out over a much longer time than while the sun is actually shining.

Without adequate thermal storage, the space will overheat during the day, and freeze at night in winter. Thermal storage also helps keep the greenhouse cool in summer, by absorbing unwanted heat gain.

The recommended amounts of thermal storage are 4 gallons of enclosed water or 90 pounds of masonry (rock, bricks, blocks) for every square foot of glazing.

Barrels filled with water support plant beds and collect heat by day, then release heat at night. The fan ventilates the greenhouse in summer.

Dark-painted 55-gallon barrels of water are the most common form of thermal storage, because they are inexpensive, locally-available, and easily-arranged to form supports for planting beds. Flat black is the most efficient color to absorb solar energy, but a dark blue, green, or red will do nearly as well. In a typical 8 x 16-foot greenhouse, 7 to 10 barrels should be used, with as many placed in direct sunlight as possible.

Other containers that can be used are recycled glass or plastic jugs in which water has

been dyed black. They must be placed on racks to prevent them from breaking under their own weight.

Rectangular-shaped, 5-gallon honey tins or gasoline cans are ideal for use as thermal storage because they can be compactly stacked against one another with all sides touching. This arrangement saves space, eliminates the need for racks, and will absorb and transfer solar heat better than barrels.

Soil is also an excellent storage medium. Most people use it without realizing that it is acting as thermal storage. Wet soil in particular has the capacity to hold a lot of heat and to release it very slowly.

Dark rocks, brick, or concrete blocks can be used to build planting beds, flooring and wall veneer and serve the purpose of thermal storage, as well. A combination of water, masonry and earth thermal storage is often the most practical design.

In new construction, a masonry wall, usually 8 to 12 inches thick, is often used as the thermal storage between the house and the greenhouse. This shared wall has built-in high and low openings through which warm air circulates to the house. The wall itself is also heated by solar rays during the day and releases this heat to both the greenhouse and the house at night.

VENTILATION

Vents in the solar greenhouse are used to distribute solar-heated air to the house in winter and exhaust heat to the outside in summer. On cold, sunny days there will be more heat trapped in the greenhouse than the heat storage can absorb. This surplus heat is transmitted to the house through openings such as windows, doors, or built-in vents.

Ideally, there should be evenly-spaced openings high on the house wall totaling at least 0.12 square feet and low openings of at least 0.08 square feet for every square foot of glazing. This arrangement will promote natural air circulation as warm, oxygen-enriched air rises into the house, while cool air is drawn from the house. Without any mechanical devices, this "thermocirculation" will perform continuously on any relatively-sunny day.

In most cases adequate upper and lower vents to the home are not available. If a door is present and is opened during the day, an acceptable heat exchange can usually take place. When windows alone are relied upon for venting air into the home, the greenhouse may overheat. This is especially true if the room to which the greenhouse is attached is kept at a high temperature.

Heat in winter, fresh vegetables and lessons on solar energy are provided by this greenhouse at the Child Development Center at Siloam Springs.

A small thermostat-switched fan may be added to deliver automatically surplus heat to the home. Sometimes the greenhouse is adjacent to a room that is not used during the day, such as a bedroom. A small duct can be installed to carry the heated air to another area where daytime heat is more needed, such as a kitchen or living room.

Air circulation to the house is also vital in controlling the relative humidity in the greenhouse. **Relative humidity** is defined as the actual amount of water in the air, compared with the total possible amount of water the air

can hold. Humidity is closely related to temperature; the colder the air, the less water it can contain. Since a high relative humidity (75 percent or higher) leads to pest and disease problems, a cool greenhouse should be kept quite dry.

On winter days, the humidity in the greenhouse is kept down by the constant air exchange with the house. This distribution of humidified air is welcome because the heated house is often too dry.

On winter nights, when there is no air exchange to the house, the humidity levels increase, especially if there are many plants in the greenhouse. This high humidity can cause **condensation,** which is the result of warm humid air being cooled, so the air can no longer hold the moisture. Since the glazing is the coldest thing in the greenhouse, water condenses first on this cold surface. This water presents three problems:

1. Water droplets on the glazing reduce the amount of light that enters the greenhouse;
2. Water may drip onto plants, increasing pest and disease problems; and
3. Water drips onto sills, causing rot.

To avoid serious condensation problems, open the windows to the house or turn on the fan early in the morning to circulate the humidified air rapidly into the house as the sun rises and the greenhouse air heats up, it will be able to absorb any condensed moisture from the previous evening.

Outside air ventilation is of particular importance in Arkansas during the warm months of the year. In addition to shading the glazing, outside air exhaust is vital for reducing temperatures and humidity, and increasing the carbon dioxide availabilty, which plants need to grow well.

Since most of the cooling breezes in summer come from the south or southwest, it is a good idea to build **openable windows** into the south glazing. Additional vents of approximately the same area as these windows should be placed high on the side walls and roof to promote a thorough air exhaust.

All of these openings should be easily opened in summer and sealed airtight with weatherstripping in winter. A minimum of 0.30 square feet of outside vents for every square foot of glazing is required to avoid using any mechanical ventilation.

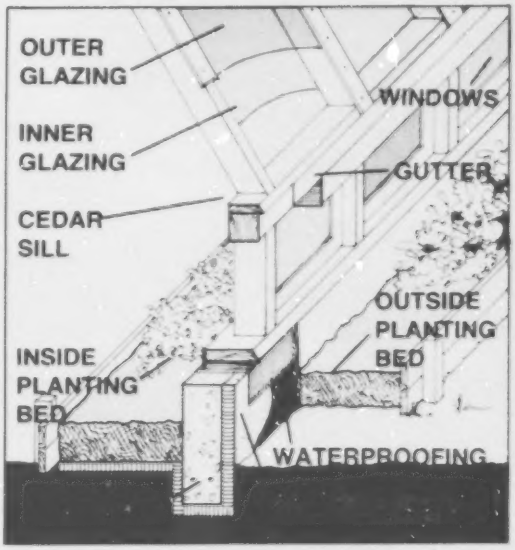
CONSTRUCTION NOTES

The most time-consuming and often the most costly part of solar greenhouses is the **foundation.** It should function as a continuous support for the structure as well as a thermal break to prevent heat loss through the ground.

Greenhouses are very lightweight structures that do not require the heavy concrete footings used for houses. Although concrete is the most permanent support, treated oak ties or treated posts are often more practical and will last for many years.

Next to heat loss through the glazing, contact with the ground offers the greatest avenue for heat loss. All foundations need to be insulated, preferably on the outside, with 2-inch rigid insulation board. The insulation should be waterproofed and extend at least 1 foot below ground.

All wall and roof areas that are not glazed should be insulated to at least R-20 and, more importantly, have a continuous vapor barrier of 6-mil polyethylene. Be sure to caulk all seams in the exterior walls, because even a small air leak can severely affect the thermal performance of the greenhouse.



Insulation and gutters control the passage of heat and moisture in this drawing of a typical kneewall assembly.

Pat Rose tends plants in a solar greenhouse she built herself.

GREENHOUSE GARDENING

Plants growing in a greenhouse are affected by several conditions different from the normal outdoor garden. Differences include altered light quality, reduced wind, absence of normal pests and predators, fluctuating temperatures and a year-round growing season.

Light quality inside the greenhouse is affected by the type and angle of glazing and reflective surfaces in the space. There will be zones of different temperature and light levels that should be recognized for rapid plant growth. Most plants have optimum growth conditions but can tolerate a great range of temperature without damage.

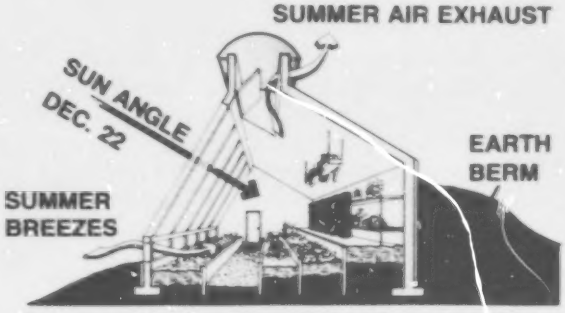
Air movement across the surface of leaves helps exchange gases during photosynthesis and respiration. Gentle winds evaporate morning dew or any accumulation of moisture on plants, which otherwise may encourage damaging fungus growth. Thorough air circulation, to the outside in summer and to the house in winter, enhances plant growth as well as thermal comfort.

Natural insect predators such as birds and frogs are, of course, absent in the greenhouse. While freezing outside temperatures kill many pests, the above-freezing condition in the greenhouse allows insects to maintain an active population year-round.

Chemical pesticides may offer a short-term solution, but integrated biological controls produce an effective long-term solution. Some insects can adapt to the toxicity levels of chemicals, and these poisons can enter our food chain.

Natural biological controls, such as ladybugs and parasitic wasps can be used to kill greenhouse pests. Careful timing in initiating biological controls, along with close observation of the plant environment, offer a safe and effective alternative to the use of pesticides in the greenhouse.

Finally, healthy plants need a healthy soil. Try making your soil from equal parts of unsterilized organic top soil or earthworm castings, peat and vermiculite. A depth of 12 to 16 inches will allow most plants ample space for good root development. A soil test is recommended to see if the proper Ph value has been achieved.



This community greenhouse plan, featuring beds of earth and water barrels for heat storage, and a protective earth wall on one side to control heat loss in winter, was developed by the Arkansas Energy Office for the Opportunities Industrialization Council of Little Rock.

NOTE: These entries are only starting points for those interested in solar greenhouses. The lists are not all-inclusive and inclusion does not imply any endorsement by the Arkansas Energy Office.

This solar home built in Madison County by Albert Skiles features a greenhouse.

APPENDIX A

SUMMARY OF DESIGN REQUIREMENTS FOR ARKANSAS SOLAR GREENHOUSES

To avoid using mechanical ventilation or auxiliary heat, **FOR EVERY SQUARE FOOT OF GLAZING,** you will need:

1.3	SQUARE FOOT OF FLOOR AREA (MAXIMUM)
0.20	SQUARE FEET OF OPENINGS TO THE HOUSE (MINIMUM)
0.30	SQUARE FEET OF VENTS TO THE OUTSIDE (MINIMUM)
4	GALLONS (33.4 POUNDS) OF ENCLOSED WATER OR 90 POUNDS OF MASONRY (MINIMUM)

APPENDIX B

COMPARATIVE GLAZING CHART

		Cost Per Square Foot	Size	Trans-mit-tance	Weight Pounds Per Square Foot
GLASS	Tempered	$ 1.80	28, 34 or 46 x 76"	0.89	1.60
	Window	1.25	varies	0.90	1.60
FIBERGLASS	Filon	0.62	4' x 50'	0.86	0.25
	Sears	0.55	3' or 4' x 25'	0.86	0.25
	Kalwall	0.96	4' or 5' x 50'	0.88	0.29
PLASTIC	Lucite	1.14	4' x 8'	0.92	0.73
	Twinwall (two layers)	1.25	4' x 8'	0.89	0.50
	Acrylite (two layers)	2.15	6' x 8'	0.93	1.00
FILMS	Polyethelyne	0.03	8, 10, or 12 x 100'	0.80	0.03
	UV-Polyethylene	0.05	14, 16, or 18 x 100'	0.80	0.03
	Vinyl	0.60	28" or 36" x 50'	0.91	0.03
	Tedlar	0.60	64" x 100'	0.95	0.03
	Flexiguard	0.38	4' x 150'	0.89	0.05

APPENDIX C

SOLAR GREENHOUSE SUPPLIES

Suppy's Greenhouse Supply ($2.00 catalog)
120 E. 12 Ave.
Kansas City, Missouri (816) 842-3071
Shade cloths, fans, glazings, temperature devices, thermal curtains, greenhouse accessories.

Brother Sun
Rt. 6, Box 10A
Augua Fria near Siles
Sante Fe, NM 87501 (505) 471-1535
Solar glazing, shading devices, window insulation, and greenhouse accessories.

Barrington Industries ($2.00 catalog)
P.O. Box 133EY
Barrington, IL 60010
Over 1,000 different items, including glazings, vents, shading devices, and many other accessories.

Zomeworks
P.O. Box 712
Albuquerque, NM 87103
Unique solar water heaters and movable insulation systems for solar greenhouses.

The Peoples' Solar Source Book ($5.00)
Solar Usage Now, Inc.
450 East Tiffin Street
Bascom, OH 44809 (800) 537-0985
Prefabricated greenhouse kits, temperature devices, fans, window greenhouse, glazings, vents, and many other active and passive devices.

APPENDIX D

ATTACHED GREENHOUSES

An Attached Solar Greenhouse
Bill & Susan Yanda
The Lighting Tree
P.O. Box 1837
Sante Fe, NM
17 pages $2.50

David Kruscks' Greenhouse
Minin Tech Solar
Rt. 2, Box 280
Wild Rose, WI 54984

Great Little Greenhouse and Solar Heater
Shawnee Solar Project
211½ West Main
Carbondale, IL 62901
$5.50

Main Attached Greenhouse
Conrad Heeschen
Sunsystems
Dryden, NE 04225
$9.00

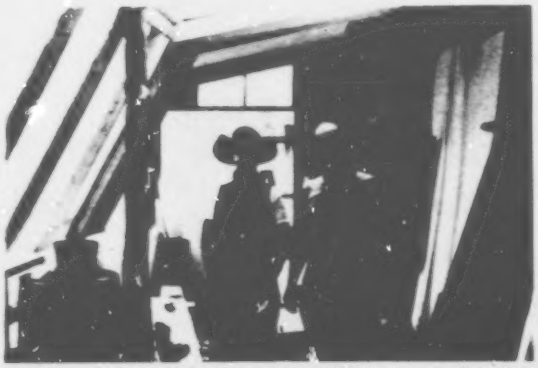
Attached Passive Solar Greenhouse Plans
Solestic Designs Inc.
P.O Box 2043
Evergreen, CO 80439
$20.00 — 8 blueprints, charts, tables

FREESTANDING SOLAR GREENHOUSES

Brace Research Institute
MacDonald College of McGill University
St. Anne De Bellevue
Quebec, Canada 49x ICO
Write for list of plans

Conrad Heeschen
Sunsystems
Dryden, ME 04225
$14.00

Solstice Design Inc.
P.O. Box 2043
Evergreen, CO 80439
$14.00



Pat and Lyle Pinkley are adding a greenhouse to their Carroll County home.

APPENDIX E

SOLAR GLAZING

MANUFACTURERS

Kalwall Corporation
Solar Components Division
P.O. Box 237
Manchester, NH 03105
(603) 668-8186
Fiberglass glazing, fiberglass water heat storage tubes.

Filon Division of Vistron Corporation
12333 Van Ness Avenue
Hawthorne, CA 90250
(213) 757-5141
Fiberglass glazing

Sears and Roebuck and Co.
3625 Truman Road
Kansas City, MO 64127
Fiberglass glazing

American Acrylic Corporation
173 Marine Street
Farmingdale, NY 11735
(516) 249-1129
Lumasite fiberglass acrylic sheets

CY/RO Industries
859 Berdan Avenue
Wayne, NJ 07470
(201) 839-4800
Double skinned acrylic and polycarbonate sheets

Park Energy Company
Star Route Box 9
Jackson, WY 83001
(307) 733-4950
Polycarbonate double glazing

Rohm & Haas Company
Independence Mall West
Philadelphia, PA 19105
(215) 592-3000
Polycarbonate double glazing

ASG Industries, Inc.
P.O. Box 929
Kingsport, TN 37662
(615) 245-0211
Glass glazing

Glass Factory
Taos, NM 87571
(505) 758-9344
Glass glazing

3M Manufacturing Company
Special Enterprises Department
Building 223-2-2W
St. Paul, Minnesota 55101
(612) 733-0306
Plastic films (flexiguard 7410)

Featherlite Manufacturing Company
Industrial Park
Malvern, AR 72104
337-7526
Glass glazing

APPENDIX F

SOLAR INFORMATION SOURCES

Arkansas Energy Office
One State Capitol Mall
Little Rock, AR 72201
(800) 482-1122 or (501) 371-1370

Solar Energy Research Institute — SERI
Information Systems Division
1617 Cole Boulevard
Golden, Colorado 80401

The National Solar Heating and Cooling Information Center
P.O. Box 1607
Rockville, Maryland 20850
(800) 523-2929

The National Center for Appropriate Technology
P.O. Box 3838
Butte, Montana 59701
(406) 404-4572

SELECTED BIBLIOGRAPHY

NOTE: These entries are only starting points for those interested in solar greenhouses. The lists are not all-inclusive and inclusion does not imply any endorsement by the Arkansas Energy Office.

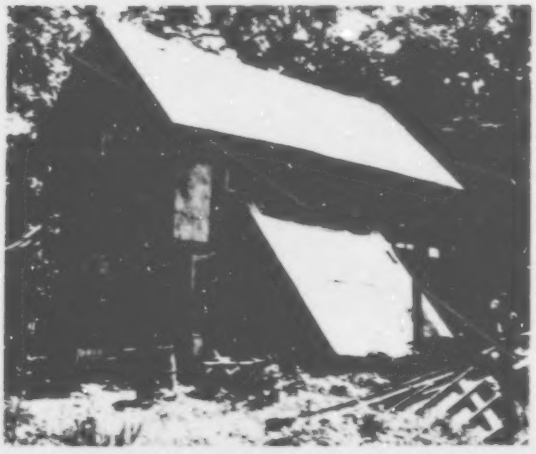
SOLAR GREENHOUSE DESIGN AND CONSTRUCTION

BOOKS

The Solar Greenhouse Book. James McCullagh. Rodale Press, 33 E. Minor Street, Emmaus, PA. 18049 $8.95 328 pages. The most comprehensive book to date on the design, construction, and management of various solar greenhouses throughout the country.

The Food and Heat Producing Solar Greenhouse. Rich Fisher and Bill Yanda. John Muir Publications, P.O. Box 613-R, Santa Fe, NM. 87501 $9.50 161 pages. The classic beginners' book on solar greenhouses with good advice on plant management, space utilization, and construction details.

The Complete Greenhouse Book — Building and Using Greenhouses from Cold Frames to Solar Structures. Peter Clugg and Derry Watkins. Garden Way Publishing, Charlotte, VT. 05445 $8.95 285 pages. Provides criteria for design of all types of greenhouses, with emphasis on solar structures. Excellent sections on plant diseases, soils, and growing conditions, with many fine drawings and photographs.



This 19th-century homestead in Benton county is acquiring a greenhouse of recycled materials with other modern features, at the hands of the owner, Rhonda Dixon.

The Passive Solar Energy Book. Edward Mazria. Rodale Press, 33 E. Minor St., Emmaus, PA 18049. An excellent resource of passive solar fundamentals, including step-by-step design methods for solar greenhouses. Used as a text book for many solar courses.

Proceedings of the Conference on Energy Conserving, Solar Heated Greenhouses, 1977. John Hayes and Drew Gillet, Eds. Marlboro College, Marlboro, VT 05344; $9.00; 282 pages. A survey of innovative solar greenhouse projects by greenhouse owners, university researchers, and representatives of community groups. Most papers include illustrations and photographs on greenhouse design and construction, and a few papers address production methods.

Proceedings of the Second, Third, and Fourth National Passive Solar Conferences. American Section, International Solar Energy Society, R.I.A.T — Hwy 190 Killeen, TX 76541; (817) 526-1300. The best books available on the state-of-the-art of passive solar design in the USA. Each volume includes a section of domestic, community, and commercial solar greenhouses. Write the American Section of International Solar Energy Society for prices and membership information.

Passive Solar Design Handbook — Vol I. National Technical Information Service, U.S. Dept. of Commerce, 5285 Port Royal Road, Springfield, VA 22161; $13.24; 320 pages. A comprehensive study of passive solar heating and cooling techniques, with a particularly good chapter on "attached sunspace". Written by Bruce Anderson.

Fish Farming in Solar Greenhouses. Amity Foundation, Solar Greenhouse Digest, P.O. Box 10010, Phoenix, AZ 85064; $6.00. How to raise domestic fish for food in solar greenhouses, both small and large.

PERIODICALS

Solar & Greenhouse Digest, P.O. Box 10010, Phoenix, AZ 86016; $10/bi-monthly. The only magazine devoted entirely to solar greenhouses. Valuable information at a low price.

Solar Age, P.O. Box 4934, Manchester, NH 03108; $20/monthly. Solar greenhouse issues: Nov. 1977; June 1979; June 1980.

Alternative Sources of Enegy, Milaca, Minn. 56353; $15/bi-monthly. Solar greenhouse articles: No. 18, July, 1975; No. 27, August, 1977; No. 36, March 1979.

New Shelter, Rodale Press, Emmaus, PA 18049; $9/monthly. Solar greenhouse issue: February, 1980.

Mother Earth News, P.O. Box 70, Hendersonville, NC 28791; $15/monthly. Many articles on solar greenhouses too numerous to mention

PLANT MANAGEMENT

Biological Management of Passive Solar Greenhouses. National Center for Appropriate Technology, P.O. Box 3838, Butte, Montana 59701. An excellent annotated bibliography on solar greenhouse production methods, biological pest control, and horticulture. Also includes a unique resource list of individuals and groups experienced in construction and management of passive solar greenhouses, and a list of companies which sell beneficial insects.

The Survival Greenhouse. James B. DeKorne Walden Foundation, P.O. Box 5, El Rito, NM 87530; $7.50; 165 pages. The author describes two years' experience growing vegetables, rabbits, fish, and worms in an underground solar greenhouse. The book contains one of the few honest assessments of hydroponic systems, both chemical and organic.

How To Grow More Vegetables Than You Ever Thought Possible On Less Land Than You Can Imagine. John Jeavons. Ecology Action of the Midpeninsula, 2225 El Camino Road, Palo Alto, CA 94306; $4.00; 81 pages. A step-by-step description of the French Intensive methods of gardening which can appreciably increase crop yields. Especially appropriate for greenhouses where growing space is limited.

The Secret Life Of Plants. Peter Tompkins and Christopher Bird. Avon Books, 959 Eighth Avenue, New York, NY 10019; 1973; $1.95; 416 pages. Has very little to do with greenhouses but is an astonishing account of the physical, emotional, and spiritual relations between plants and people. Highly recommended for anyone who grows plants.

Horticultural Management of Solar Greenhouses in the Northeast. The MEMPHREMAGOG Group, P.O. Box 456, Newport, VT 05855. This manual was written to share the successes and failures that many solar greenhouse owners have had growing food crops. Provides basic information on how best to use the structures to produce food.

Organic Gardening Under Glass. George and Katy Abraham. Rodale Press, 33 E. Minor St., Emmaus, PA 18049; $8.95; 308 pages. Though written for the hobbyist who is using a conventional structure, most of the information is also applicable to solar greenhouse growing. For a range and depth of coverage, this book on organic gardening is hard to beat.

MOVABLE INSULATION AND SHADING METHODS

Solar Control and Shading Devices. Olgyay and Olgyay. Princeton University Press, Princeton, NJ; 1957.

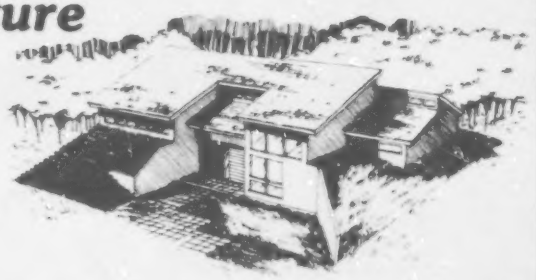
Design with Climate. Victor Olgyay. Princeton University Press, Princeton, NJ; 1963. These two books are classics in the field of passive solar design, even though they were written before energy became an issue in building design. They contain much valuable information on solar control which can never go out of date.

Selecting and Growing Shade Trees. U.S. Department of Agriculture, Washington, D.C.

Thermal Shutters and Shades. William Shurcliff. Brick House Publishing, 3 Main Street, Andover, Mass. 01810; $12.95; 238 pages. The most complete book to date on homemade commercialy available insulating devices for windows.

Arkansas Energy Future

Earth Homes



INTRODUCTION

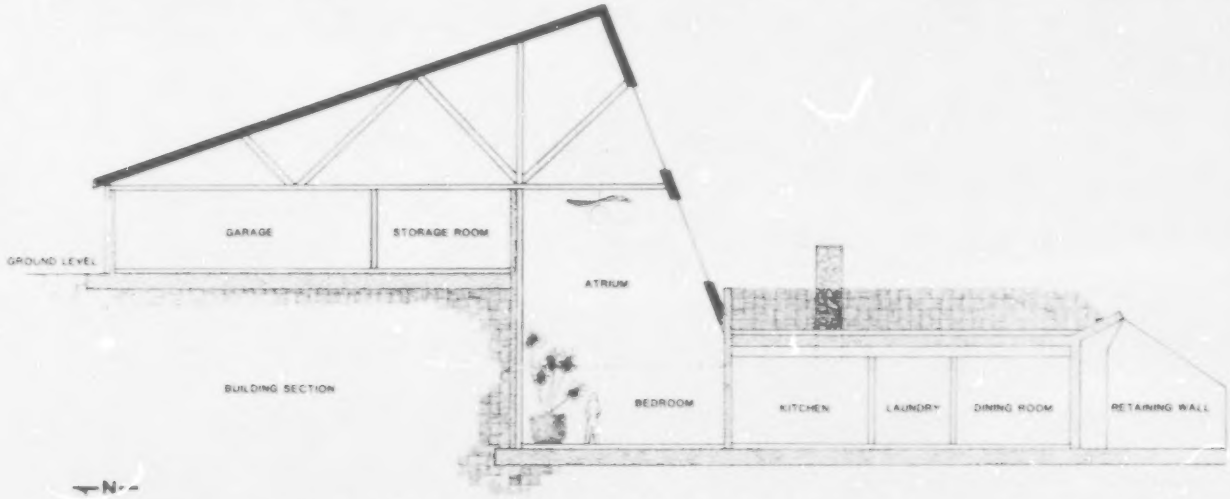
Several years ago, the person who covered his house with dirt was rare and considered, at best, a little weird. Today, people are beginning to realize the many benefits of an earth-sheltered home. Some of the benefits include how quiet and peaceful they can be, the protection they offer from tornadoes and other storms, the fact that they can be brighter and far airier than most aboveground dwellings, the ease with which they can be cooled during the summer, low fuel costs, minimal maintenance, and superior durability.

Today, there are still many members of our society who have yet to discover earth-sheltered homes and the benefits they offer. People do not compare the costs of earth-sheltered homes to the aboveground structures most live in now.

BUILDING TECHNIQUES

When you build underground, you have to give a maximum amount of thought to picking out materials that won't deteriorate under constant contact with the soil. You must also choose materials that can carry the weight of all the dirt and rocks you intend to pile up on the roof. And of course, you must make sure that your structure is well-drained and waterproofed.

If the residence is constructed so that the entire structure is one thick slab of concrete after another and the mass of concrete is insulated on the outside with three inches of polyurethane foam sheeting, this adds up to an efficiency that few dwellings can match. In other words, a home underground with massive concrete walls that are well insulated on their outside surfaces maintains its interior



This cross-section illustrates the two levels of the Richard Stortie home near Sidney, Arkansas

at a constant and even temperature . . . no matter how hot the atmosphere above it gets in the summer, or how cold that air becomes during the winter. That helps keep utility bills low.

There are three fundamental design possibilties for an earth-sheltered house: elevational, atrium and penetrational.

The elevational concept involves a semirecessed building backed into a sloping site. Floor plans must be carefully designed if each room in the house is to have a view of the outside world through a window. There are only windows on the exposed elevations — preferably on the south side.

The atrium design is a fully-recessed house, built around a central opening. The length, width, and depth of the atrium have an effect on lighting, ventilation, and solar heating possibilities in an underground building.

In a penetrational design, natural light and fresh air reach the living space through gaps either left open or dug into the earth around the perimeter of the structure. The design does not take full advantage of the effectiveness of earth covering. This type of home will need more retaining walls than either of the other two types of designs.

External surface is not as important for earth-sheltered houses as it is for aboveground shelters. Living spaces should be designed with maximal floor area and minimal wall surface.

A second story should be professionally-engineered, and built only of reinforced concrete. Never use a wooden joist system. Excavation for a two-story underground house is very expensive, and backfill material must be compacted with special care.

More than likely, a house underground will not contain either attic space or basement area. Also, essential columns, shear walls, and other internal supports limit spatial layouts and make plannng more involved than usual.

Mechanical rooms or units are sometimes needed to store water-heater and air-conditioning units. These mechanical rooms can sometimes be hidden in back closet corners and disguised beneath entryway steps. Do not give up on the idea of aboveground storage; this may be needed at a later time.

An aspect of the underground house that calls for special attention is the entryway. The entryway should be open, pleasant, recognizable and inviting. It should be separate from the more private windows of the house, and receive people gracefully, without disturbing others already inside the house.

Wooden foundations should not be labeled

This earth home near Sidney, Arkansas, is being built by Richard Storlie; it features an atrium 32 feet high, which admits sunlight into many rooms in the home.

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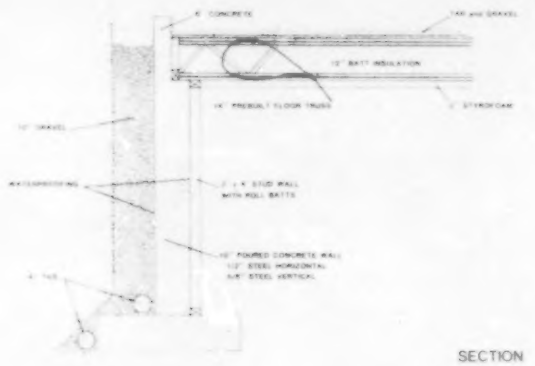


SECTION

The Fayetteville home of Randall Webb features a layer of gravel next toe the house wall, to allow moisture to drain away.

"taboo". Some new wood preservatives can now legally be used underground. These include chromated copper arsenate salt preservatives, which are odor-free, permanent, safe and sound. The wood is protected against rot and insect damage.

Wood foundations are attractive and the installation process is relatively easy. A wood foundation is easy to insulate and finish on the inside. To start, a two-by-ten pressure-treated sill is laid on a level bed of compacted sand or gravel. A standard studwall with plywood sheathing is then built on top of this sill, all out of a pressure-treated lumber and rust-proof nails. A six-mil black polyethylene moisture barrier is carefully glued to the outside of the plywood foundation wall.

Do not backfill until after the floor slab is poured and the roof members are all in place. After the foundation has been gently banked with earth that can't puncture the polyethylene, it should be strong enough to withstand pressures.

Once pressure-treated lumber has been cut, it should be painted with more preservative. This should be done periodically so the wood will last longer than redwood and cedar. Possible life expectancies range from 40 to 80 years.

SITING

The lay of the land needs to be studied closely before deciding which type of earth-sheltered housing best suits a particular lot. The quality of the site may also determine the number of people who will eventually live there. Ideal sites for underground homes are sunny most of the day, so the house can be heated by the sun in winter. In summer, solar heating will have to be reduced, perhaps by a cantilevered roof that overhangs and shades any windows that face south.

It may be helpful for you to carry a pocket compass and refer to it often when looking for a suitable underground site. Southern exposure should be the number-one consideration. When the house is actually oriented

FLOOR PLAN

Randall Webb of Fayetteville provides space for a future bedroom in the earth home he built.

on the site, its windowed side should face close to true south.

Look for mountains or hills that block low incoming rays from the sun during the winter. Broadleaf trees should let sunlight through, once they lose their leaves in the fall.

When picking a site for an earth-sheltered home, surface water must be taken into account — even if it's not there at the moment. A house that is dug into a poorly-chosen site may end up perpetually wet.

The topography of the land influences wind patterns, vegetation, and shading, and limits the way roads and buildings can be planned. The northwest side of the house requires the most protection, in the winter-time. Use the hillside itself (if there is one); use an artificial mound of earth; and, possibly, form a windbreak of shrubs and trees. The very best building sites will slope gradually away from severe winter winds — towards the warmth of the sun.

Your neighbor's building should not obstruct your sun rights. Nor should your excavation undermine someone else's foundation. Many times adjacent homes may interfere with your sunlight. Check to make sure excavating and pouring concrete walls underground will not change the flow of subterranean water, or affect the homesites of adjoining landowners.

Another possible problem is "ledge", which is bedrock that is too close to the surface. Ledge also means unacceptable leaching conditions for sewage disposal. If there are no environmental laws to insure against it, the health of the whole neighborhood may be endangered. Ledge could also mean an added expense if expensive drilling and blasting are used to create underground space for the home.

Shallow soil at the site is another problem. There should always be enough space for the storage and transportation of dirt from one place to another, without encroaching on the neighbors.

Because earth-sheltered homes are still a novelty to some people, the lack of privacy can be a problem. Once the word gets out they exist, everyone wants a look. Many times unexpected or uninvited visitors will appear at a window.

Rooftops, especially, should be protected from heavy equipment operators who either don't know or forget they are there. One suggestion is to use an "approach control" — an electronic warning or closed-circuit television camera to make an unexpected arrival less abrupt. A simpler solution would be to provide privacy in the sloping of earth berms, roof plantings, retaining walls and landscaping at the very beginning.

Another fringe benefit of earth-sheltered homes is natural soundproofing. The noise-dampening qualities of soil offer the perfect cure for noise pollution. Planes can roar overhead and trucks can rumble past, hardly noticed. You will never know what passed above you.

The following suggestions will be helpful to you in determining the suitability of a site:

1. Take at least one soil boring extending to a depth of approximately 10 to 20 feet below the proposed foundation — unless bedrock is encountered or knowledge of local conditions makes this depth unnecessary.
2. The types of soil should be logged as the boring proceeds. Soil samples should be taken and kept in airtight jars.
3. The depth at which ground water appears should be noted.
4. If the ground water table is close to the footing depth of the structure, a perforated plastic pipe can be installed to collect the water, so that the ground water table and any fluctuations in it can be monitored.
5. A testing firm or consulting soil engineer or agency, such as the Arkansas Geological Commission, the Arkansas Soil and Water Conservation Commission, or federal Farmers' Home Administration, should comment on the suitability of the site based on their information. They should recommend design values for allowable foundations loads and lateral earth pressure.
6. To keep the soil-testing costs low, it will help if the potential position of the house on the site and some major parameters of the design have been considered; the closer to the surface the house is built, the fewer problems

the builder faces.

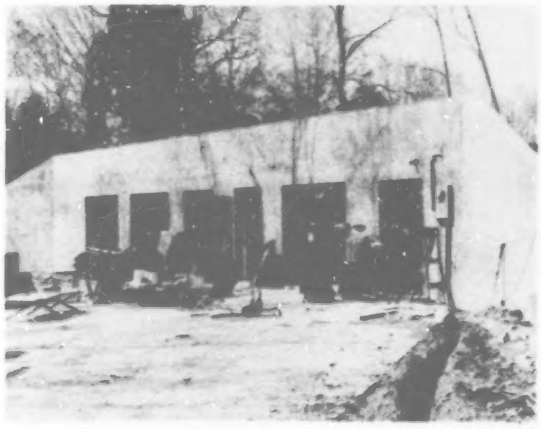
7. A percolation test soil-boring program is always required when a septic tank and drain field are to be used. Check the state plumbing code, or call the Arkansas Department of Health at 661-2000, in Little Rock.

SOIL CONDITIONS

The climate of the earth itself is one aspect of earth-sheltered structures that is misunderstood . One cannot appreciate the advantages in building beneath the surface without an understanding of the principles of soil temperature and heat flow in undisturbed soils. An understanding of these fundamentals is also necessary for effective use of the earth for heat exchange and heat storage.

SOIL CLIMATE

Moisture content has the greatest influence on heat conduction. The soil's tendency to transport heat from one place to the next is called "thermal conductivity". It is very important to make sure that soil adjacent to concrete walls be porous enough to drain well. Sand and gravel are best. The better the drainage system, the less heat will be drawn away from the house. Fine-grained soils close to the surface are more susceptible to frost heaving because they hold water more easily. Wet top-soil banked against a concrete wall, even above porous backfill, can become a major heat-loss artery.



This Conway earth home being built by Sonny Ethridge features cement walls on the southern exposure — a common practice in this housing style.

There are other factors that cause soil temperatures to vary, including latitude, site characteristics, weather conditions, and the nature of soil particles themselves.

Soil shows very little temperature fluctuation from day to day, below 18 to 20 inches, regardless of the surface temperature.

Each foot of soil means a seven-day time lag in temperature variation. At eight feet, it could be two to three months before soil particles show a transition from summer warmth to wintertime cool. Below 12 feet, temperature variations hardly exist.

Soil depth is a great heat stabilizer. Normal soil temperatures well below the surface in most parts of the world average about 55° F year round. Earth-sheltered homes are best suited, then, to areas where climate varies from season to season — places where people spend lots of money on insulation and energy, either to warm or cool themselves.

SOIL ANALYSIS

Soils are classified according to types. One type, sand, usually feels gritty between your fingers and has visible grains. If the grains are larger than two millimeters in diameter, the substance is known as gravel.

A second major soil type is silt. Its grains are much smaller than the sand. Silt grains cannot be seen with the naked eye.

A third type, clay, is slippery to touch. When dry, clay has billions of flat microscopic particles that stick to each other; they slide past each other when they are moistened. Clay is not the ideal soil to use against an underground wall. It is called "cohesive soil". A cohesive soil is one that expands when wet. This kind of expansion plugs up most drainage passages when wet. It can exert enough pressure against a weak concrete wall to crumble it like dry bread crust.

For small structures such as a house, strength and loading parameters of the soil are usually estimated, from the soil description, and use of simple empirical measures such as a penetration test, which involves forcing a probe into the soil and measuring the force or

number of blows needed to move the probe a certain distance.

The soil type of a potential earth-sheltered site should be determined before any effort is expended on either the site or the design for the house. A site investigation should be done before the land is purchased, to determine whether or not the site is suitable, or too costly a site on which to build.

BEARING STRENGTH

Structures have to be strongenough to withstand earth pressures. Weight-bearing characteristics hold true across the nation. Some examples of weight-bearing capa cities of products include:

Bedrock	200,000 pounds per square foot or 100 tons
Foliated Rock (Bedded limestone, hard granite)	40 tons per square foot
Gravel and hard pan	10 tons per square foot
Coarse sand	4 tons per square foot
Wet sand	2 tons per square foot

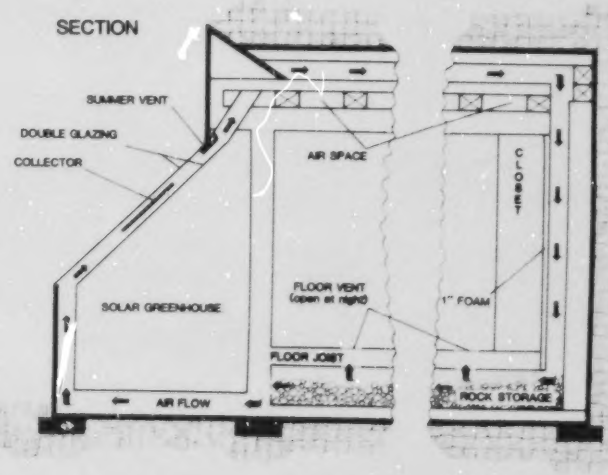
Most underground homes will not exert more than 1.5 tons (3,000 los.) per square foot. The only soil that has unsuitable bearing is soft clay, with a maximum capacity of one ton per square foot.

The condition needed for most conventional construction is to excavate upper soil layers deep enough to establish a flat "pad" in "undisturbed subsoil". All soil should be mechanically compacted as the first step in construction.

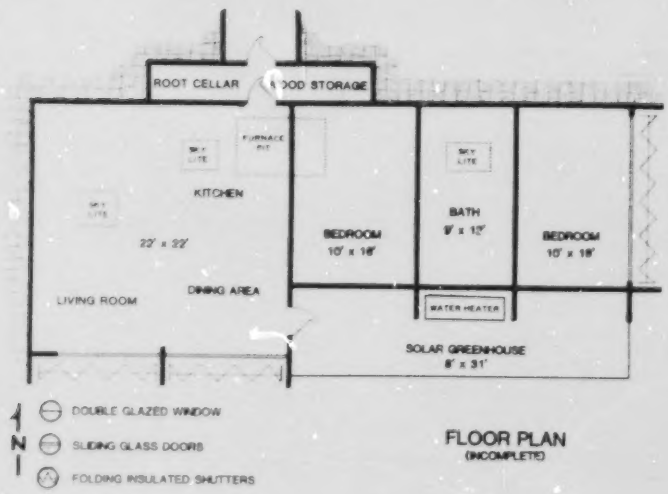
ROOF SOIL

Roof soil must drain well. Spreading topsoil over a layer of sand or gravel will usually accomplish this. What is planted on a roof depends largely on the depth of soil there. Generally, there should be one to three feet of soil on the roof. If more soil is added, the roof is stressed excessively and becomes extremely heavy.

Less than a foot of soil provides too little thermal mass to make the earthen roof worth



Cross-section of the Harold Meyer house plan shows use to be made of sunlight and woodstove heating, and the general house ventilation pattern.



FLOOR PLAN
(INCOMPLETE)

Harold Meyer of near Yellville plans to build this earth home, featuring woodstove heating and a rock pit to hold the heat. Details of the house plan are not yet final.

BEST COPY AVAILABLE

the effort, and limits the growth of vegetation. Topsoil should drain readily above a layer of sand or gravel, and it should probably be mulched at first. More than five feet of soil would be needed to support large shrubs or small trees.

Rooftop vegetation may be started by borrowing plants from another part of the building site. Vegetables can grown on a roof as easily as lawn, though they will need more care.

The temperature of roof soil will be affected by the nature of its cover vegetation. Green growing things shade the moist ground — cooling it. They also transpire, giving off some of their moisture to the surrounding air, thus cooling themselves.

WALLS

There are large differences in the lateral pressures on walls among different soil materials. A sand or gravel backfill immediately adjacent to the wall, which will drain ground water to the foundation drain, should be used when considering the structural design of the walls in conjunction with the drainage and waterproofing requirements. Expansive clay should be avoided. It swells and exerts high pressures when wet. Soft clay at the site can present problems of excavation slope stability and difficult site conditions during construction.

FOUNDATIONS

Bearing capacity of the soil is the major parameter here. The foundation loads of the walls will be much higher than for conventional structures. Soft or loose deposits of soil should be avoided. Special care should be taken when dealing with existing man-made fills.

STRUCTURAL ANALYSIS

Naturally, one of the most important concerns in any earth-sheltered house is structural strength. (Statistics have shown that three feet of soil, when covered with a foot of snow, will exert 360 pounds per square foot of pressure on the surface below.)

The building's ability to withstand the heavy roof loads and tremendous lateral or side pressures is not understood by all builders.

In most cases, the roof load is handled with footings of ample dimensions. Avoid placing center bearing beams on columns with small footings that cause the roof load to push the footings into the ground. With the roof dished to the center forming a trap for snowmelt and rain, a greater load is placed on waterproofing.

In earth-sheltered construction, another problem is lateral, or side, pressure. Because of the tremendous amount of pressure that can be exerted against the wall, pilasters and internal reinforcing should be considered. The wall can bend or crack, and in the case of light construction, such as fiberglass panels or wood frame, the whole house can be shifted on the footings.

There are two categories of structural systems available for earth-sheltered housing. The first group includes the more conventional systems, such as concrete walls with precast or poured concrete roof structures, as well as steel-and-wood post-and-beam systems. The second group consists of a variety of more unconventional structural systems, including concrete and steel arch and dome shapes, which have unique potential for earth-sheltered structures.

Many rules of thumb are applicable in the structural design of earth-sheltered homes. The earth-sheltered house is many feet underground and has a significant earth load — approximately 120 to 140 pounds per square foot (for each foot of depth) of earth cover.

The structural form of the house has an important impact on the ease with which the heavy loads can be carried. The earth-sheltered construction does not have much flexibility in the design, like above-ground construction. If unique requirements of earth-sheltered construction are not considered, a higher price than necessary will be paid in structural costs. Placement of doors and windows in the structural wall must be planned with more care, because of the heavier loads.

STRUCTURAL MATERIALS

One of the most commonly-used materials in below-grade buildings is reinforced concrete. Whether it is poured in place, precast or

pretensioned, reinforced concrete is cheap and strong, and has a much longer life span than conventional materials.

Heavy timber roof systems are acoustically and thermally superior to concrete, and cost about the same amount, if they are within certain span and load limitations.

Concrete block is sometimes used for exterior walls. However, block does not last as long as concrete and is porous. The cost is about the same as concrete when reinforced properly with rebar, which is a steel reinforcing bar, and poured-in-place top course, which caps the top of the wall.

Pressure-treated lumber and plywood have been used for exterior wall, below-grade purposes. However, the cost is about the same as, or more than, concrete, and the thermal storage potential is relatively low.

Concrete is the most flexible, tough, all-purpose material available for below-grade buildings. When proper detailing at corners, edges and openings is used, earth-sheltered buildings of concrete have a longer life expectancy than structures that use other materials.

WATERPROOFING

Once the site has been selected and preliminary layouts and landscaping made, waterproofing should be next on the list. The waterproofing of an earth-covered structure is very important. Usually, earth-sheltered homes are surrounded by potentially-waterbearing material and therefore rigorous waterproofing practices are essential. The greater depth of the building means greater water pressure. Water in the soil on the roof can stay there for days — and the slightest leak can cause unsightly damage.

A dependable waterproofing installation begins with a good surface on the part of the structure that is to be earth-covered. This means that the side walls must be free of sharp edges and protrusions. The roof should be smooth, with no low areas on it. When a poured-in-place concrete roof is used, it is customary to pour the roof flush with the edge of the wall. However, in precast plank construction, the planks end somewhere near the centerline of the walls, leaving a step configuration. This area should be capped off, forming a smooth angle. The more corners, edges or protrusions, the more difficult it is to waterproof.

Trees shade this earth home built at Fayetteville by Randall Webb.

SOURCES OF MOISTURE PROBLEMS

An atrium design that is located completely below grade has a much greater potential danger in a low-lying area. Structures of this type are not naturally self-draining and drainpipes and possibly some pumps must be installed to handle any water that collects in the court area. These drains and pumps would not be capable of handling a large flow of surface water, but are sized to handle expected rainfalls or ground water flows. You should also avoid sites that are potential gullies for surface runoff during heavy rains.

If at all possible, avoid a high water table. In the case of high water in a very permeable material, a drainage system may not be able to drain the area fast enough and a substantial waterproofing system must be applied to the entire structure.

TEMPORARY WATER PRESSURES ON WALLS

Heavy rains may cause seepage of water into the ground adjacent to the house. Sloping the ground away from the house will prevent this. Properly compacting the backfill, so that it does not slump to trap water, will prevent this. This effort also ensures that large voids are not left, which can fill up with water.

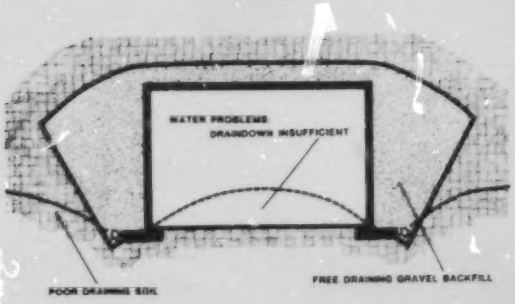
Temporary water pressure can occur under many circumstances. This can happen when the foundation of a house is above the water table; or it can occur in the spring, because the ground closest to the house usually will thaw first, due to the heat loss from the house. The buildup of temporary water pressure is the biggest complication in designing a moisture-control system for a foundation above the normal water table. Temporary water pressure can seldom be eliminated.

DRAINAGE TECHNIQUES

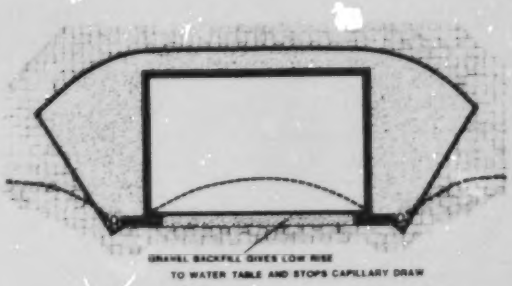
Drainage techniques reduce the frequency and duration of water conditions that actually test the membrane. Use of drains to lower the ground water table will also eliminate the necessity of structurally designing the walls or floor for water pressures. Drains should be located as low as possible with respect to the foundation and finished floor level, if they are to be used to permanently lower a water table.

Here are some pointers:

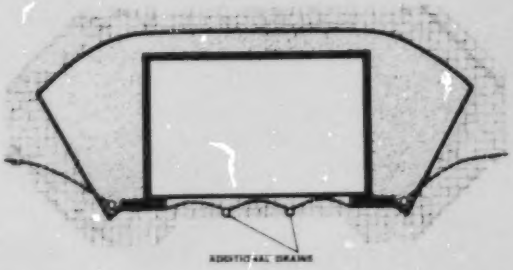
1. Backfill should be a freely-draining material, except for a capping of soil of low permeability.
2. Backfill should act as a filter to prevent the washing of clay and silt particles from the surrounding ground through the backfill and into the drain. There are various design-filter-fabrics that can be wrapped around the drain to prevent clogging. Some examples of these are fiberglass cloth and aluminum screen wire.
3. The water table should be kept below floor level with only perimeter drains; the drawdown curve of the water table should be shallow.



A freely-draining material should be used for the backfill.



Gravel backfill is used here as a drainage technique that gives low rise to water table and stops capillary draw.



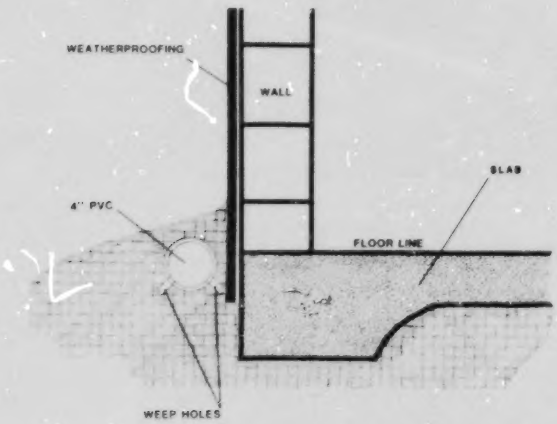
Additonal drains are always needed underneath the home.

4. Drains should be able to drain naturally on a sloping site. If draining is impossible, the water must be pumped up and allowed to flow away or sprinkle out over the ground surface.
5. Access for cleaning out the foundation drain should be included in the design.

DRAINAGE
(OUTSIDE PERIMETER)

The drainage can be accomplished by putting a four-inch polyvinylchloride pipe, known as PVC, schedule-40 drainpipe, around the perimeter of the house, with a one inch downward slope per 10-foot length, until the pipe surfaces are ground level at a point lower than the floor of the house.

At least three to four inches of gravel should be placed around the PVC to cover it. Kraft building paper or a similar material should surround the gravel. The kraft paper will cause water to run to the side rather than run through the gravel.



Drainage for outside perimeter of a home is provided by pipe and weep holes.

DAMPPROOFING

Dampproofing products are those that will prevent moisture in the soil from penetrating the structure, but will not prevent the entrance of water. There are no guarantees on dampproofing products, but they can help dampness problems in some instances. Some dampproofing techniques are:

Concrete mix design and additives
Parge-coating the wall (with a dense cement plaster)
Asphalt coating
Pitch
Polyethylene sheet
Liquid seals

WATERPROOFING METHODS

Built-up membranes consist of layers of asphalt or pitch alternated with felt or fabric reinforcing. Three to four piles are considered a minimum for waterproofing purposes. Because felt will rot if it becomes exposed to water, glass-fiber fabric should be used. A disadvantage of any membrane is that if leakage occurs in one place, adhesion is not able to prevent water from traveling behind the membrane and appearing inside at a point remote from the actual leak. Locating a leak is difficult as well as expensive for an earth-sheltered structure. Most membranes are susceptible to damage between the time they are applied and inspected and the time after they have been backfilled. Membranes should be elastic enough to bridge cracks in the structure or have a resealing ability.

Bituthene is a rubberized asphalt. It comes in liquid form or wide rolls. Bituthene has an elongation capacity of 300 percent and is self-sealing around small punctures. Although it is sensitive to ultraviolet radiation, it can be protected with coatings or counter flashings where exposed to the sun. It is not recommended under continuous water pressure. When applied to roof surfaces, the membrane should have a slight slope, to give positive drainage for the roof.

Butyl rubber, epdm, and neoprene membranes have good bridging charactristics. Major problems are in making the proper seams between the sheets of material under field conditions. A technique called compartmentalization is sometimes used to reduce the travel of water from a leak. The leak can be found easier and the material can be completely bedded down.

Liquid applied polymer membranes do not need seams and are useful for awkward areas and around vent pipes. These have no resealing ability. They are not recommended for use on a precast roof system.

Bentonite panels are made of cardboard material that encloses bentonite clay. When the panels come in contact with water, the clay expands tremendously. The clay seals itself

against further penetration by water as it tries to expand. It has resealing ability due to its swelling characteristic. It should not be used where running water could slowly carry the bentonite away from the wall, nor where there is a high concentration of salts in the ground water, since this interferes with the swelling mechanism. It is not degradable and won't break down or decompose.

Waterstops are most effective when used to reduce water leakage at cold joints or expansion joints in concrete. Most leakage occurs in joints in poured concrete walls, floors, etc. Therefore, it is necessary for joints between waterstop sections to be perfect. Waterstops have gripping and stretching power. A waterstop is sheeting poured in with a bulb on each end.

Flashing details are used in treatment of corners and projections such as skylight wells or roof vents. These flashing details represent the weak link in the system. Generous laps should be provided, and fillets are often used as corners to avoid sharp changes in direction.

When considering waterproofing, makeplans around these issues:

1. What time of year will you be making the installation?

2. How well qualified is the installer?

3. Know the type of surface that will be needed for installation —concrete, wood, etc.

4. What will be the condition of that surface (rough, smooth)?

5. Be familiar with the moisture content of the soil. If the moisture content is high, the footings and lower level of the wall will always be moist, due to capillary action of the concrete.

6. Never apply a loose-laid membrane to a roof; an adhesive is necessary to prevent water vel of the migration under the membrane in case of a leak.

7. Do not use conventional roofing systems underground, such as asphalt or pitch membrane.

8. No product is appropriate for all jobs.

9. Take proper precautionary measures, because your building may develop leaks.

10. If you are faced with moving joints, do not rely on every product to stretch across them.

11. Do your own homework relative to the choice of your waterproofing product. Do not rely solely on your architect or contractor.

12. Know the physical characteristics of the soil on which the structure will be built.

13. If you are planning to purchase an underground home that has been constructed by others for resale, do not purchase that home if dampproofing materials have been used to waterproof the vertical wall. Obtain a written statement as to the type of waterproofing that was used and the guarantee provided.

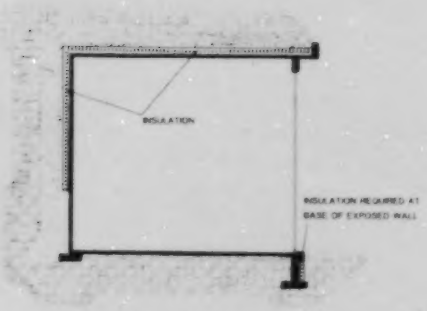
CLOSING

In any waterproofing system, it is important to remember that the areas treated should always be on the outside of the building. This way, the insulation protects the waterproofing from a puncture and isolates the waterproofing from outside temperatures.

INSULATION

Earth-sheltered structures should be insulated with artificial materials just like any other structure, despite the mistaken notion that soil itself is a good insulator.

To take advantage of the structure's capacity for thermal storage, insulation should be placed on the outside of the building, on the roof, walls, and even under the floor slab, in a thin layer. In warm, dry climates, insulation on lower walls and the slab should be omitted. Since the roof is the area of greatest heat transfer in any climate, it will require the most



Insulation is needed at base of exposed wall to prevent heat from draining away into the earth.

insulation; the next greatest need is insulation for the walls; and then comes the insulation need of the slab.

Placement of insulation outside the structure allows the mass of the house to be located within the insulation envelope. Such mass prevents unwanted rapid temperature changes in the interior spaces. This also eliminates condensation problems. Insulation should be placed inside the structure only as a last resort.

If there are parts of the house that are not covered with concrete, masonry, or metal, then heat can easily be conducted throughout parts of the house.

MATERIALS

The following characteristics of insulation materials are desirable when placing insulation on the outside:

1. High compression strength, to resist backfilling and soil pressures.

2. High resistance to water, and very low water absorption, so the R-value of the insulation is not reduced.

3. High resistance to the various chemical properties of soils; therefore, long-lived.

4. Good dimensional and R-value stability over a long period of time; the ideal insulating material for earthsheltered construction has a life expectancy of at least 20 years.

5. Tongue-and-groove configuration to reduce cold spots and water movement between the insulation sheets.

6. Low-cost, easily-handled, and presently-available.

Important chacteristics for inside placement:

1. Fire resistant, or high resistance to the production of poisonous fumes during fire.

2. Life expectancy of at least 20 years.

3. Low-cost (low-cost = maximum long-term R-value per dollar spent; an insulation that has a high first cost, but long-term properties).

4. High R-value per inch of thickness to minimize interior space loss.

A few commonly-used insulating materials are extruded polystyrene, urethane and fiberglass. Polystyrene, commonly known as Styrofoam, is a closed-cell insulation foam that refuses to absorb moisture. Extruded polystyrene is the most suitable material for use outside. Urethane is another material, which insulates somewhat better than polystyrene, but often has open cells that will receive water. Some older types of urethane can soak up water and become waterlogged. In some areas, it is also attractive to ants and other insects.

If inside insulation must be used, fiberglass may be the most suitable material, because of its low-cost and reduced-performance requirements for internal insulation. Both polystyrene and Styrofoam are manufactured in a closed-cell form and are suitable for wet, below-grade installations. Each is strong enough in compression to use under typical floor slabs. The recently-developed inverted-roof systems, which place the waterproofing membrane directly on the deck and the insulation above it, have been developed with both polystyrene and urethane specified. The decision on how much to use should be determined by R-value guidelines established for specific geographic locations. for specific geographic locations.

Since insulation comes in board form, in one-inch thickness increments, the ideal

variation in cross section can be achieved by using one-inch insulation near the bottom, and increasing in thickness by one or two-inch layers towards the top of the wall. Insulation is available in other size increments. An uninsulated concrete wall or slab is an excellent conductor and is bound to assume the temperature of the earth behind it.

It has been found that below-grade insulation, laid horizontally above a wall, is more effective than an equivalent amount of the same material laid vertically against the wall.

VENTILATION

There is no need to be concerned about unwanted smells or stale air in an earth-sheltered home. Earth-sheltered structures in particular offer the occupant the benefit of minimal unwanted air infiltration; one may control the amount of exhaust and make-up air required by ventilation. Ventilation is necessary for the following reasons:

- To supply the proper amounts of oxygen for the health and well-being of the occupants.
- To supply the proper amounts of oxygen necessary to combustion if open-flame furnaces, fireplaces, etc. are in the home.
- To dilute or eliminate excessive moisture in the air during the summer.
- To dilute or eliminate odors generated in the bathroom or kitchen.
- To dilute or eliminate the heat produced by internal sources during the summer.

In an earth-sheltered construction, a forced-air heating system is the most advantageous for ventilation. Make-up air is easily provided with this kind of system. Several methods are available for introducing fresh air into a house with a forced-air heating system. Consult your architect in order to select the most effective method needed for your home.

Other basic systems that can be used for heating as well as cooling the living space include the forced-air duct system, hot water baseboard system, gravity air system, and radiant system.

FLOOR PLAN

Because of the limited exposed wall available for windows, more care must be taken in designing the floor plan of an earth-shelterd house than in a house above ground.

One of the objections to earth-sheltered housing that is most often voiced is the lack of windows. If well designed, the house does not have to be a dark hole in the ground, but can be a light, airy, bright environment.

Actually, a studied attempt should be made to furnish all areas with natural lighting and ventilation. This may lead to the use of thin horizontal windows at the top of interior walls, to "borrow" light without losing privacy, and the greater use of atriums to furnish natural light to back rooms, even in houses cut into south facing slopes.

Priorities for rooms to receive natural light will vary from person to person, but general guidelines can be offered. The highest priorities will usually be given to living rooms, dining rooms, dens, and kitchens, with bedrooms falling into the second category. Bathrooms and utility rooms would come next with storage rooms a distant last. This category would also include wine cellars and mushroom farms.

Always check with all relevant codes and regulations for requirements for windows before finalizing your floor plan. Call the city building inspector or planning commission office for guidance.

SELECTED REFERENCES

BOOKS

Campbell,Stu. *The Underground House Book.* Storey Communications, RD#1, Box 105, Schoolhouse Road, Pownal, Vermont 05261, 0-88266-166-2, $9.95.

Underground Space Center. *EarthSheltered Housing Design: Guidelines, Examples and References.* University of Minnesota, 1978.

K.B. Labs. *The Architectural Use of Underground Space: Issues and Applications.* Underground Design Research, 174 Livingston Street, New Haven, Connecticut 06511, 1975, $20.00.

ARTICLES

Alternative Sources of Energy. The August, 1978, No. 33, issue and the September/October, 1979, No. 39, issue are devoted to underground and passive buildings.

The Construction Specifier, "Human Spaces Underground — An Old/New Technology", W. Neal. 31(1):39-50, January,1978.

Popular Science, "Underground Houses—Low Fuel Bills, Low Maintenance, Privacy, Security", V. Smay, 210(4):83-89, 155, April, 1977.

Earth Sheltered Digest and Energy Report, "Waterproofing — Do Your Homework", Bryan McGroarty, 23-27, January/February, 1981.

TECHNICAL BRIEF

DESIGNING THE PASSIVE SUNSPACE

The passive sunspace is an attractive option to both the builder and the homeowner because of its dual function. Besides contributing a significant portion of a home's space heat, it provides bright, airy living space that can serve as a recreation or dining area. This **Technical Brief** *describes basic functioning of passive sunspaces and offers guidelines for designing and sizing them.*

SUNSPACE DEFINED

The passive sunspace is a separate room attached to the south side of a house with a south wall that consists primarily or entirely of glazing. It is a non-mechanical solar collector that functions by admitting solar radiation during the day through large expanses of south-facing glass and transforming the radiation into heat. A portion of this heat is absorbed and stored by heat storage mass within the space and some of it heats the air. This heated air flows from the sunspace into the house through operable windows, vents, fans, or doors. When the temperature in the sunspace falls, the storage mass releases its heat to the space.

In addition to providing heat, a sunspace acts as a buffer, protecting a portion of the building from severe outside temperatures and winds.

ORIENTATION

Like other passive systems, the sunspace must be oriented to face as close to true south as possible. It must also be positioned to receive unobstructed winter sunlight. Though perfect southern orientation is best, the sunspace can face within 30 degrees east or west of true south and still function well. Any greater variation will impair winter heating and may create overheating problems from east or west sun during the summer.

SUNSPACE DESIGN

The type of design selected for the sunspace will vary according to what use, apart from heating, the space will be put to. Generally speaking, the most efficient sunspace design in southern climates is one with vertical glazing on the south face, a solid roof, and little or no glazing on the east and west sides. The solid roof provides shade to the sunspace during summer, and the east and west walls block the morning and afternoon sun. In winter, sunlight will penetrate the sunspace on the south side, because the sun is at a lower angle and will not be blocked by the roof. The solid east and west walls provide insulation *(see Figure 1)*.

The type of sunspace just described is basically a sun porch and can be adapted to a variety of uses as a living area while it is providing heat to the home. In summer, exterior blinds or shades, combined with the roof and its overhang, block most of the sunlight, making it usable even during the day.

Some homeowners may elect to use their sunspace as a greenhouse for growing plants. This approach allows horticulture during colder parts of the year for less energy cost than a conventionally heated greenhouse. However, it should be noted that using a sunspace in this way can compromise its heat contribution to a residence, especially when the selected plants require warm temperatures both day and night. If a sunspace is used for plant growing, some overhead glazing may be required, but this glazing must be fully shaded from the outside in summer.

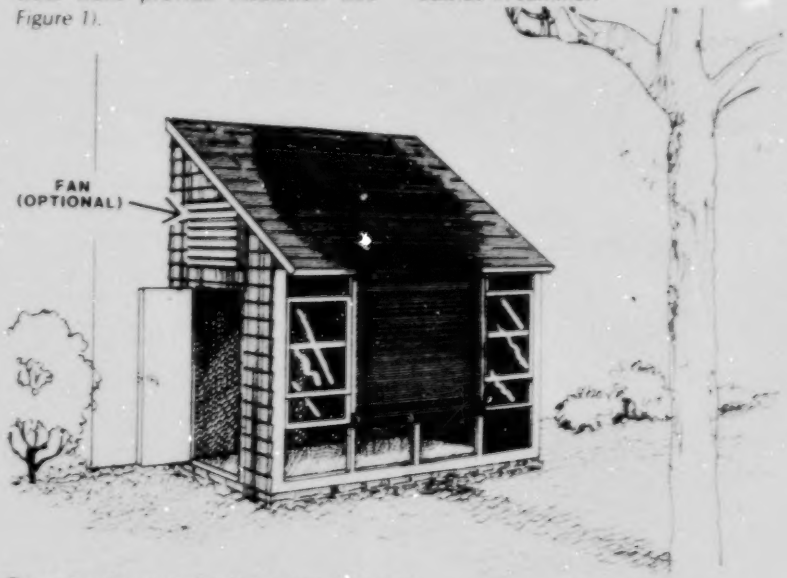


Figure 1 A sun porch-style passive sunspace

Sizing the Sunspace

The sunspace functions best when its depth is kept between six and twelve feet. A depth of at least eight feet is necessary when the space will be used as a living area with furniture. The length of the space should be greater than the depth to provide more surface area for glazing and, consequently, solar collection.

Thermal Mass

Successful sunspace design is based on a careful balance between the sizing of the glazing and the sizing of the heat storage or "thermal" mass. Thermal mass – which can be tile, brick, masonry, or water – functions by absorbing and storing solar radiation as heat. When the temperature around the mass is higher than that of the mass, it absorbs heat. When the surrounding or ambient temperature is lower, the mass releases heat. In this way, thermal mass can help prevent the sunspace from overheating during the day and can furnish heat to the space at night when temperatures fall.

As a rule of thumb, about three to five gallons of water or 120 to 200 pounds of masonry should be included in the sunspace for every square foot of south-facing glazing. The larger the amount of mass, the lower the daily temperature swing and the greater the comfort level. However, too much mass may prevent the air in the sunspace from heating sufficiently to provide useful heat to the house.

Water is easily the least expensive of storage materials. One pound of water will store the same amount of heat as 4.3 pounds of concrete or 4.8 pounds of brick. Water also takes up less space. A cubic foot of water has the same heat storage capacity as 1.9 cubic feet of concrete or 2.5 cubic feet of brick. Two factors, however, affect these relative costs. (1) Water needs a storage container. If inexpensive steel drums or discarded gallon jugs are used, the container cost is minimal. But if decorative containers are used, the storage cost can equal that of brick or concrete. (2) Masonry storage mass can be applied as a brick or tile floor in which case, the dual use offsets the higher cost of the masonry.

COMPARISON OF GLAZING MATERIALS

TYPE	BRAND	PERCENTAGE TRANSMITTANCE	COST*
Glass			
Single glazing			
Window		85	1
Double strength		85	1.3-3.0
Tempered		85	4
Double glazing		71	5.3-12.0
Triple glazing		60	9.3-13.3
Acrylics			
Single wall	Plexiglass	92	1.3-2.6
	Lucite	92	1.3-2.6
	Acrylite	92	1.3-2.6
Twin wall	Acrylite SDP	85-92	2.2-4.0
	Cor-X-Acrylic	85-92	2.2-4.0
	220 Twin Wall	85-92	2.2-4.0
	Polylux	85-92	2.2-4.0
Polycarbonates	Merlon	86	3.0-4.3
	Lexan	86	3.0-4.3
	Tuffak Twinwall	82-89	1.6-2.3
Fiberglass	Lascolite	79-80	.3-1.1
	Filon	79-80	.3-1.1
	Sunlight	85-90	.3-1.1

*Cost is based on single glazing equal to 1.

Masonry or water containers for thermal mass should be dark colored to increase heat absorption and should be positioned to receive direct winter sun. All interior surfaces that do not function as storage should be light-colored to help reflect the sun's energy to the storage mass materials.

Glazing

There is a great deal of flexibility in the amount of south-facing glass used. Generally speaking, as much south glazing as desired may be added if: (1) the glazing is correctly balanced with thermal mass; (2) summer shading techniques are employed; (3) the wall between the sunspace and the house is well insulated; and (4) the sunspace is fully vented in summer to achieve at least one air change per minute. In any case, it is unlikely that more than 25 to 30 percent of a home's floor area in south-facing glass would be practical.

There are several types of glazing available that are suitable for use in sunspaces. The above table compares various glazing materials in terms of both cost and their ability to transmit sunlight. The higher the transmittance of the glazing, the larger the amount of solar radiation that will be received.

There are some special considerations in selecting glazing.

- Frosted or diffusing glass may be preferred if privacy is a concern. Many plastics are inherently light-diffusing; however, some yellow with age or exposure to sunlight. Only plastics designed for outdoor use should be selected.

- Any sloped glass surface should be constructed of safety glass.

- When selecting glazing, it is best to work in standard sizes that are readily available in the event sections need to be replaced.

Summer Venting

Some provision must be made for venting air from the sunspace to the outside during warm weather to prevent overheating. Ventilation should provide at least one-half of an air change in the sunspace per minute and as much as a full air change per minute for very large glazed areas.

Vent openings to the exterior equal to one sixth the floor area are adequate for natural ventilation. There should be both inlets and outlets, with inlets positioned low and outlets positioned high in the wall. Double-hung windows or high and low awning or hopper windows work well.

If mechanical ventilation is preferred, a small fan can be built into the east or west wall to move hot air from the sunspace to the outside.

Winter Air Circulation

Provision must be made for controlled air circulation between the house and the sunspace in winter to move the collected solar energy into the living area for heat. What type of circulation is used will depend on the design of the house and whether it is a new house where several options may be considered or an existing one where circulation must be adapted to the existing wall.

Circulation can be achieved through operable windows, doors, vents, or a thermostatically controlled fan. Total vent opening, be it window, door, or vent, should be equal to at least five percent of the covered wall area for natural circulation. The opening should be one that can be closed completely. When vent openings are used, they should be placed both high and low on the wall for the best natural circulation. Hot air rises and enters the home from the sunspace through the high vent. Cool air from the home enters the sunspace through the lower vent.

There are three basic ways in which heat can be exchanged between the sunspace and the adjacent living space. Often these methods are combined to provide winter air circulation.

1. Direct radiation and conduction – Heat passes from the sunspace to the home by radiation through glass doors and windows in the intermediate wall. When the doors or windows are opened, the heat flows directly into the interior of the home *(see Figure 2)*.

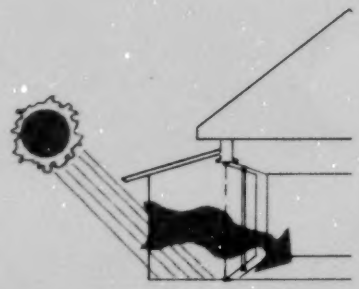


Figure 2. Direct radiation and conduction.

2. Natural convection – A conventional wall may be constructed with grille or louvered vents placed at the top and bottom to transfer heat from the sunspace to the house and vice versa by natural convection. In winter, cool air from the house enters the sunspace through the lower vent, which should be an operable register or a return air grille with a backdraft damper. Warm air rises to the top of the wall and enters the home through the upper vents. This cycle continues as long as there is sufficient temperature differential to force the air to rise. This type of circulation system is well suited to retrofit applications where an existing wall can be modified to include upper and lower vents *(see Figure 3)*.

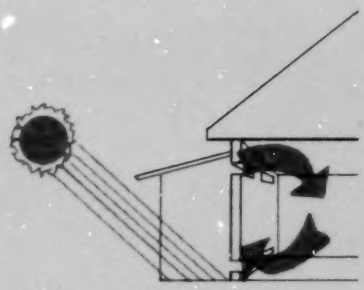


Figure 3. Natural convection.

3. Forced air – Fans can be used to enhance natural convection to move air back and forth between the sunspace and the home or to move heat deeper into the house. In this system hot air is forced into the adjacent space by a fan, and air from the living space is returned to the sunspace via a return air grille with a backdraft damper. The fan may be controlled by a thermostat that turns it on automatically when sunspace temperatures are high enough to provide useful heat to the home *(see Figure 4)*.

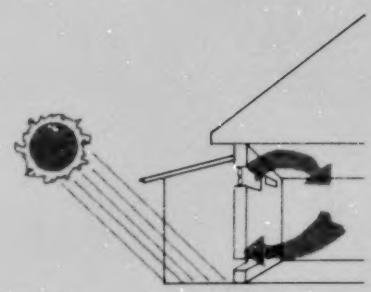


Figure 4. Forced air circulation *(fan is located in an upper vent)*

Insulation and Weatherization

Insulation levels in the sunspace should be the same as those in a well insulated house. Exterior perimeter insulation is extremely important to prevent heat loss from the slab edge *(see Figure 5)*.

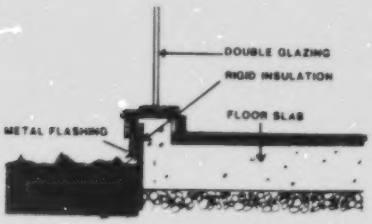


Figure 5. Perimeter insulation prevents heat loss from the slab edge.

Extra care should be applied in the installation of the glazing. The large window areas of the sunspace increase the potential for air infiltration, so caulking should be handled carefully. Also, the edges of any operable glazing should be weatherstripped.

Double glazing is recommended for latitudes above 32 degrees north; however, many designers recommend its use in all locations.

Shading and Night Insulation

To make the sunspace comfortable during the summer and to prevent it from increasing air-conditioning loads, shading of one or several types must be employed. A roof overhang, sized to admit low winter sun but block the high summer sun, is recommended. The overhang will block only direct radiation, so an additional form of shading, such as blinds or shades, are necessary to block diffused or indirect sunlight. (Indirect solar radiation can account for 50 to 80 percent of the total solar radiation entering the sunspace.) Exterior shading is much more effective than interior shading because it blocks the solar radiation before it enters the home. Several types of weatherproof shades and blinds are available for this purpose.

Landscaping can also provide shade. Deciduous trees or vines provide shade in the summer, but lose their leaves in winter to admit sunlight through their branches. Trees with dense branch patterns may still block too much sunlight even when bare of leaves and may require pruning if located on the south side of the sunspace.

During winter months, heat loss from the sunspace at night can be reduced by using movable insulation. This can take the form of rigid panels or insulated drapes or shades. The latter are more popular because they are easier to use. Night insulation can increase heat production from the sunspace by as much as 20 to 30 percent in cold climates and can prevent very cold nighttime temperatures, which would harm plants. However, its benefit is insignificant in most of the South, since sunspace temperatures will not fall below freezing even without night insulation. Around latitude 35°N, greenhouse sunspaces begin to benefit more from night insulation.

SOURCES OF INFORMATION

Several publications are available that discuss the design and sizing of passive sunspaces. The following are recommended.

Anderson, B., ed. *The Solar Home Book*. Harrisville, NH: Cheshire Books, 1977.

Eccli, R., *Low-Cost Energy-Efficient Shelter for the Owner and Builder*. Emmaus, PA: Rodale Press, Inc., 1976.

Fisher, R. and Yanda, B. *Solar Greenhouse: Design, Construction, and Operation*. Santa Fe, NM: John Muir Publications, 1976.

Lucas, T. *How to Use Solar Energy*. Pasadena, CA: Ward Ritchie Press, 1977.

Mazria, E. *The Passive Solar Energy Book*. Emmaus, PA: Rodale Press, Inc., 1979.

Watson, D. *Designing and Building a Solar House*. Charlotte, VT: Garden Way Publishing, Inc., 1977.

HOW MUCH ENERGY DOES A SUNSPACE SAVE?

The answer to this question will vary from one house to another. Even two identical houses can experience different energy savings from a sunspace depending on the lifestyles of the occupants. Another consideration is whether the sunspace is part of a new home that has been designed to maximize solar performance or whether the sunspace is retrofitted to an existing home that does not interact as well with the sunspace.

One house design with a sunspace passive heating system was recently evaluated to predict how much energy a prospective owner could expect to save as a result of the sunspace. Predictions were performed by an engineering team using various solar design tools that took into consideration such factors as floor area, size of glazing and thermal mass, and climate factors. It was estimated that on a new 1,538-square-foot home,* a 236-square-foot sunspace would reduce annual heating bills by 40 to 80 percent. The lower figure was for the northernmost southern states (Virginia and North Carolina) and the higher figure was for middle Florida.

Retrofit sunspaces generally provide lower energy savings, somewhere in the 20 to 30 percent range. However, depending on design, retrofits can save much more.

*Apollo model, Mayhill Homes, Inc., Gainesville, GA

1982

TECHNICAL BRIEF
BUILDING ENERGY DESIGN TOOLS

Building energy design tools have been developed to help architects, engineers, and builders design energy efficient structures. Currently available design tools range from simplified manual rules-of-thumb to computer programs that model the heating and cooling loads of buildings and can even simulate a specified building's thermal performance. The development of building energy analysis computer programs is a relatively new and rapidly growing field. This Technical Brief describes the types of computer energy analysis tools available that can assist in building design.

WHAT ARE COMPUTER DESIGN TOOLS?

Computer energy design tools are software that can be used to analyze the effect of certain design variables on a building's thermal performance. Depending on the individual program, the variables may include climate, insulation levels, infiltration control measures, quantity and location of windows, thermostat settings, and different types of passive solar systems. Some programs also include the capability for analyzing the benefit of overhangs, movable insulation, operable shading devices and various ventilation techniques. With a computer program, a designer can make well-founded decisions about various design options in a fraction of the time it would take to do manual thermal analysis calculations. Also, with the larger computer tools, a greater accuracy can be achieved than with hand calculations. Thus, a designer can look at and compare a greater variety of features that can lead to reduced heating and cooling loads.

Most computer design tools are programs that do not require extensive knowledge of computers in order to obtain useful results. However, it is important to understand that the computer does not do the designing or engineering for the user – it only does calculations. The use of computer energy design tools requires the skills of a person who is familiar with thermal characteristics of buildings. The user should also be knowledgeable about the particulars of the program being used because the results are very sensitive to the assumptions and limitations of the software.

Another factor which should be noted is that most computer tools are based on well-defined methods for calculating the heat loss or heat gain effect of certain features. They simply perform the many complex or time-consuming calculations very quickly so that the designer can compare and evaluate a number of design variables. Generally, standard ASHRAE algorithms are used in programs that give heating and cooling loads. Most programs that analyze the annual thermal performance of passive solar systems for residential applications are based on the Solar Load Ratio (SLR) method developed by researchers headed by J. Douglas Balcomb at Los Alamos Scientific Laboratory. The SLR method, which is described in the *Passive Solar Design Handbook – Volume 2*, provides a monthly performance estimate based on a broad range of variables including collector area, heat loss rate, shading, reflectors, night insulation and amount of thermal mass (see Reference citation).

Regardless of the particular application, it is important to know the methodology of the program under consideration. The documentation for the program, which explains its methodology, should be reviewed to determine whether the program will yield useful results for a specific application.

HOW COMPUTER DESIGN TOOLS ARE USED

Energy analysis can be effective throughout the entire design process, from developing the design concept and design schematics to preparing final designs and construction documents. The energy performance of a building depends on design decisions that are made at the very beginning of the design process as well as the fine-tuning details of the final design documents. In fact, some of the earliest design decisions that deal with the configuration and orientation of the building and its placement on the site are often the most critical. The best design tool for energy analysis will vary, according to the complexity of the application as well as the developmental stage of the design process.

Generally, early in the conceptual design process, quantitative analysis will be limited to the manipulation of broad design parameters, such as glazing amounts or insulation levels. This type of analysis will most likely be the only kind appropriate for residential applications. As design development progresses on more complex structures, typical parts of the building can be isolated for more detailed analysis, including simple parametric analysis.

When a basic design is completed and the investment in the building warrants more detailed analysis, a computer program can be used to determine the performance of the entire building over an extended period of time. Parametric analysis at this stage can help with decisions about construction details and materials that must be made based on

their energy performance. Final quantitative energy analysis of the completed design can also provide data for documenting a building's compliance with energy codes.

Although the earliest design decisions have the greatest impact on a building's energy performance, the appropriate energy analysis tools for early design decisions are simpler and less costly than those that would be used later in the design process. In fact, large scale computer simulations that can be used to fine-tune design and construction details can be very expensive and time consuming. Consequently, this type of analysis would be appropriate primarily for large scale commercial construction when a sizable investment is involved.

As an example of how a computer energy analysis program can be used for early residential design decisions, Figure 1 shows the results of an analysis performed with SLR-PLUS. The program was used to compare the heating load of a base house in Columbia, South Carolina, with 40 square feet of south-facing glass area and the same house with a 250 square-foot direct gain passive solar system. The heating load of the house when R-5 night insulation is used with the direct gain system was also calculated for comparison purposes. As the chart illustrates, a direct gain system can significantly reduce the home's heating requirements. The heating load is decreased even more when R-5 insulation is used at night to reduce heat loss through the large glass area of the direct gain system. Thus, the passive solar direct gain feature would be beneficial on this particular house design in the Columbia location.

This is just one example of how a computer tool can help a designer evaluate the thermal performance of certain design features. There are a large number of computer programs that analyze the energy performance of buildings, which can be used as energy design tools. The different computer programs available vary according to their capabilities, methodology, input requirements, accuracy, cost, and the type of computer equipment they require. A convenient way to categorize computer programs is by the size of computer needed to operate the software.

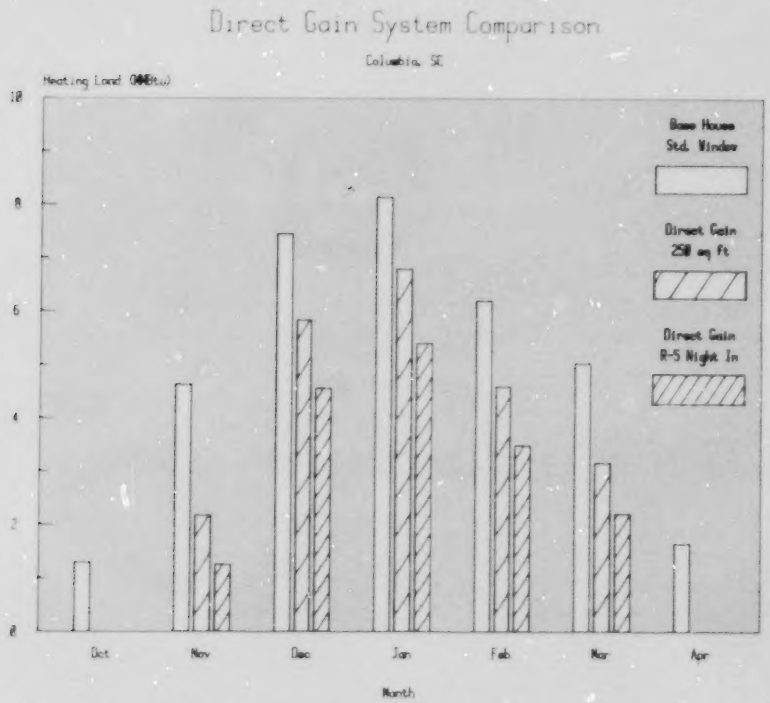


Figure 1. Comparison of a conventional design and a direct gain passive solar system.

MICROCOMPUTER MODELS

A number of building energy analysis programs are available for microcomputer systems. Microcomputers have received increased use because of their reduced cost and improved performance resulting from new electronics technology. Many programs function with one specific microcomputer. However, with the clear trend toward standardized operating systems (the control program which manages the computer system), a large number of programs can be used by several microcomputers with relatively minor changes in the set-up process. These computers usually come with a video terminal, a processor with 64,000 words of memory, and a small printer – all at a cost well within the means of small businesses and many individuals.

Most microcomputer programs use correlation equations and multi-variate analysis to calculate a building's heating load based on certain variables, such as climate, orientation, insulation levels, and glazing area. Some will also calculate the building's energy costs and the energy savings or payback period for certain investments. Their relatively low cost, averaging from $50 to $500, and simple input requirements make microcomputer programs suitable for typical residential applications. Of course, an easy-to-use microcomputer program is based on simplified assumptions and generalizations, which reduces its level of accuracy. Thus, these programs are best used for making comparisons among features rather than for predicting actual energy consumption or economics.

One example of a microcomputer model developed for making relative comparisons of energy conserving options at an early design stage is RES CALC,

developed by the Southern Solar Energy Center. The options that can be compared with this program include insulation values, alternative glazing configurations, infiltration control measures, and three common passive solar systems – direct gain, Trombe wall, and sunspace. The input requirements for this design tool are relatively simple. Once a preliminary data file has been created for specific locations, including fuel costs, HVAC equipment efficiencies, market information, climate data, and various design factors, any number of designs can be analyzed for those locations by simply entering size and cost information on the design features under study. The program results in a summary that lists the energy savings, cost savings, and payback period for the energy saving options analyzed.

Once again, the primary purpose of this particular program is to offer a simple method for calculating benefits of energy efficient options. Consequently, it should only be used to compare the relative performance and costs of options, not to project actual energy consumption and cost savings. There are other microcomputer programs which provide for more complex energy analysis. NEATWORK is a microcomputer program for passive solar design by Princeton Energy Group which permits thermal network analysis. It is a general network modeling tool for hourly simulations of up to 20 days duration. The complexity of the systems analyzed depends on the microcomputer's memory capacity, and the accuracy of the results depends on the user's ability to represent the building under study. The outputs of the program include hourly temperature and heat flow values, daily summary of heat loss, and auxiliary or excess heat at the end of each run. NEATWORK would be suitable for residential and small commercial passive solar building design.

There are also many other microcomputer programs available. The attached listing includes some of the organizations that offer microcomputer energy design tools. Since this is a rapidly growing field, good sources of information on the most current programs are engineering, architectural, and energy-related trade journals.

Contacts for Microcomputer Programs

Earth Integral
Suite 5
2655 Portage Bay Avenue
Davis, CA 95616

Ecotope, Inc.
2326 East Madison
Seattle, WA 98112

ESG, Inc. (SLR-PLUS Program)
2231 Perimeter Park
Suite 11
Atlanta, GA 30341

FCHART Software
4406 Fox Bluff Road
Middleton, WI 53562

HP-85 User's Library
1000 NE Circle Boulevard
Corvallis, OR 97330

Lawrence Berkeley Laboratory
Technical Information Department —
CIRA Project
University of California
Berkeley, CA 94720

Londe, Parker, Michels, Inc.
7436 Forsyth, Suite 202
St. Louis, MO 63105

MC 2 Programs
McClintock Corporation
Box 430980
Miami, FL 33143

National Energy Software Center
Argonne National Laboratory
9800 South Cass Avenue
Argonne, IL 60439

Princeton Energy Group
729 Alexander Road
Princeton, NJ 08540

RES CALC Project
P.O. Box 81245
Atlanta, GA 30366

Solar Environmental Engineering Company
2524 East Vine Street
Fort Collins, CO 80524

Solarsoft
Box 124
Snowmass, CO 81654

Solarcon, Inc.
607 Church St.
Ann Arbor, MI 48104

Western Wares
P.O. Box C
Norwood, CO 81423

MAINFRAME MODELS

Most mainframe programs are capable of analyzing almost any facet of a building's thermal performance. In fact, what the program can examine and how well is limited largely by the skill of the user. Although they were primarily developed to analyze the energy consumption of existing buildings, these programs are now often used as building design tools in the final design stages. The complexity of modern heating and cooling systems used in large buildings has led to the use of these large programs to size and select heating and cooling components.

The input requirements for mainframe programs are extensive, and they depend on a thorough understanding of the assumptions that must be made regarding the interplay among components and equipment and the way the program treats the input data. The user must usually input:

- All dimensions, orientation, location, construction, and materials of all exterior walls, windows, doors, roofs, foundation perimeters, including insulation materials.
- The specification of the primary and secondary HVAC system.
- Microclimate data, such as shading, reflections off surrounding buildings, terrain, etc.
- Building occupancy patterns, including number of occupants, schedule of building use, lighting requirements, etc.
- Specification of all mechanical, lighting, data processing, manufacturing, and office equipment.
- Cost information.

Other inputs that are usually provided by the software and data files are:

- Daily or hourly weather data for the site, including temperature, sunshine, winds, etc.
- "Default values" for specifications or performance characteristics not known by the designer.

The outputs of the major mainframe programs give detailed reports on building loads. Some are also capable of hourly energy performance simulations for a full year. Performance reports may include HVAC equipment duty cycles by period and day of the week, temperature distributions by zone, monthly energy re-

Table 1. Large Scale Computer Tools for Building Energy Design

Program Name	Sponsoring Organization	Comments
BLAST	U.S. Army Construction Engineering Research Lab P.O. Box 4005 Champaign, IL 61820	Evaluates energy conservation and solar options. Provides for either annual or hourly simulations with consideration of building shading and room heat balances. Has extensive library on wall sections, building materials, and HVAC system types. Outputs include monthly and daily loads, energy for different end uses, peak and average daily profiles, and life-cycle costs for each option chosen.
CALPAS3	Berkeley Solar Group 3140 Grove Street Berkeley, CA 94703	A minicomputer program that allows users to represent a single zone with any passive heating system, as well as natural and forced ventilation or evaporative cooling. Output includes monthly, daily or hourly reports of energy flows and temperature.
DOE-2	Los Alamos Scientific Laboratory Mail Stop 985 Los Alamos, NM 87545	Developed for the analysis of multi-zone buildings with standard mechanical systems and includes active solar systems options. Extended ASHRAE heat transfer algorithms allow simulation of complicated and unusual building shells. Has extensive library of wall sections, building materials, and HVAC systems. Output options allow the user to select predefined reports or to define reports or plots according to special requirements.
SOLAR-5	School of Architecture and Urban Planning UCLA Los Angeles, CA 90024	Developed as an interactive architectural design tool for use during early design stages. Uses standard ASHRAE algorithms to compute hourly incident solar radiation, sol-air temperature, total equivalent temperature difference, heat loss, and heat gain. As an aid for evaluating different building envelope designs, it provides detailed information on instantaneous heating and cooling loads and only a general approximation of annual energy consumption.
SUNCODE	Ecotope, Inc. 2328 East Madison Seattle, WA 98112	Originally developed by the National Center for Appropriate Technology as SUNCAT, this minicomputer program can evaluate passive solar systems in buildings with multiple zones. Output is monthly and annual loads by zone.

quirements by application, peak demand profiles, and life-cycle economic evaluations.

Table 1 gives a brief description of selected large scale programs that can be used for building energy analyses. Selected programs include those that can model buildings with non-conventional construction or operating systems such as passive solar designs. There are many other mainframe design tools available that primarily focus on sizing and selecting HVAC systems, including both conventional and active solar systems.

More information can be obtained on the programs listed in the table by contacting the sponsoring organization. Mainframe energy analysis software can be very expensive to purchase, costing up to several thousand dollars, and some programs can only be used through special arrangements with the sponsoring organization. Another way to access the more commonly used programs is through major computer services companies, such as CDC Cybernet Services, Martin Marietta Data Systems, and Boeing Computer Services.

REFERENCES

Analysis Methods for Solar Heating and Cooling Applications. Solar Energy Research Institute, 1981 (SERI/SP-35-232R).

Bazjanac, Vladimir, "Energy Analysis – This is Where and What," *Progressive Architecture*, April 1982, pp. 122-126.

D'Alessandro, Bill, "A Guide to Using Passive Design Tools," *Solar Age*, December 1982, pp. 28-30.

Fraker, Harrison and Lindsey, Lawrence, "Energy Design Aids – This is How," *Progressive Architecture*, April 1982, pp. 116-121.

Los Alamos Scientific Laboratory, *Passive Solar Design Handbook, Volume 2.* U.S. Government Printing Office, 1980. (Available from National Technical Information Service, DOE/CS-0127/2).

Microcomputer Methods for Solar Design and Analysis. Solar Energy Research Institute, 1981 (SERI/SP-722-1127).

Nordham, Douglas and Glennie, William L., "Choosing the Right Design Tool," *Solar Age*, November 1980, pp. 33-37.

ENERGY FACT SHEET

PASSIVE SOLAR RETROFIT

An add-on passive solar system — a passive solar retrofit — can fill a substantial portion of a home's energy needs. This* Energy Fact Sheet *presents an overview of passive solar retrofits, including how to assess your home's solar potential, how to choose the best system for your needs, and how to implement the decision to retrofit your home.

WHAT IS A PASSIVE SOLAR SYSTEM?

A passive system is a nonmechanical solar heating system that uses building components – windows, walls, and floors – to capture, store, and distribute the sun's heat. Solar radiation passes through a glass surface and heats a space. High-mass objects within the space, such as masonry walls and floors, absorb and store excess heat, which is released to the space when interior temperatures fall. In passive systems there are no mechanical collectors or pumps to convert solar energy into heat. The energy is used directly.

Since passive solar systems involve structural components of the house, they are often considered applicable only to new construction. But a passive system can be added or "retrofitted" to a house to provide a good percentage of the home's heat. Sometimes the retrofit is a matter of modifying existing windows or walls and sometimes it is a matter of adding a solar room or "sunspace." The approach taken will depend on such factors as the design of your home, the type of system that best serves your needs, and how much you want to spend.

ASSESSING YOUR HOME'S SOLAR POTENTIAL

The first step in assessing your home's solar potential is to determine how much solar exposure you have and how you can make it work for you. Using a compass, determine your home's orientation in relationship to due south. The ideal location for a passive solar system is on an external wall that faces due south; however, orientation can vary up to 15° east or west of south, and a passive retrofit will still function effectively. Variations greater than 15° reduce winter solar gains and create problems with overheating during the summer from east and west exposures.

Once you've determined that you have a wall with good southern orientation, the next step is to check its solar exposure. A basic rule of thumb is that the wall must receive direct sunlight from 9:00 a.m. to 3:00 p.m. in the winter for a passive solar system to work. If trees or nearby structures block the sun from your south-facing wall in the winter, a passive system will not receive enough sunlight to function effectively. Remember, the sun is lower in the sky in the winter than in the summer so that low objects that do not block the summer sun may block the winter sun. Deciduous trees may block the sun in summer, but they lose their leaves in winter to let sunlight through. These and other site factors must be carefully considered.

A helpful tool in assessing your home's solar access is a sun locator. These devices enable you to "see" the sun's path in both winter and summer and evaluate it in relationship to trees and structures near your house. A simplified version can be acquired free from the Conservation and Renewable Energy Inquiry and Referral Service (toll free 800-523-2929). Ask for the brochure ***Avoiding Shade on Solar Energy Collectors*** (FS-111), which contains the locator. Other sun locators of varying degrees of complexity are available commercially.

TYPES OF PASSIVE RETROFITS

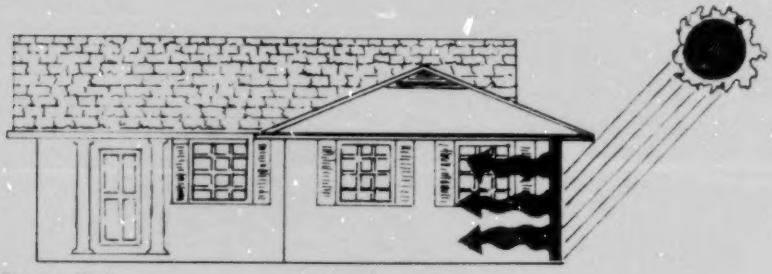
Having determined that solar orientation and exposure are adequate, the next consideration is what type of passive system is best for you. The three most popular retrofit options are direct gain, Trombe wall, and sunspace systems.

Direct Gain

Direct gain is the collection and containment of radiant solar energy within the occupied space. Sunlight enters the home through south-facing windows and heats the room. It also strikes floors and walls, which absorb, store, and reradiate heat to the home's interior. If heavy construction materials are used for these interior walls, their mass serves both to minimize drastic temperature changes from night to day and to store the heat energy for sunless periods. Thermal storage mass can consist of a concrete slab, water containers, an interior masonry wall (a chimney is ideal), or a combination of concrete, tile, and masonry that together provide the correct amount of total mass.

Trombe Wall

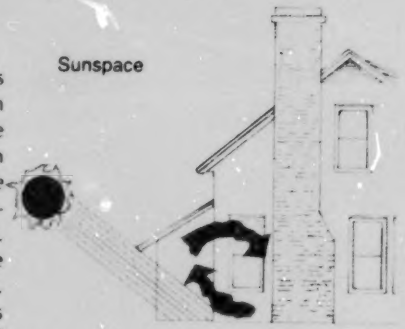
A Trombe wall is a masonry or concrete wall covered externally with a glass skin. A small air space of 4 to 8 inches is left between the wall and the glazing. Solar radiation passes through the glass and is absorbed by the mass wall. The glazing prevents most of the heat from being returned back to the outside. The mass is heated during the day and releases its warmth to the interior during the evening and night hours. Vents may also be placed in the wall to permit heat to flow directly into the room during the day.



Trombe Wall

Sunspace

A sunspace is a glazed room that is part of or attached to a home but which can be completely closed off from the main living area. Sun enters through south-facing windows and warms the room. This warm sunspace air is then circulated to the home's interior for heating. Techniques can be employed to store the heat and prevent daytime overheating. One method is to include thermal mass to absorb excess heat during the day and release it at night.



Sunspace

PREVENTING OVERHEATING

Passive systems that provide heat in the winter will go on providing heat in the summer unless measures are taken to block the summer sun. The most effective measure is a combination of roof overhangs, external shutters or shades, and landscaping to keep the summer sun from entering the home. Unless these measures are employed, the system will continue to heat the home in summer, increasing air conditioning loads and cancelling the net energy benefit of the passive system.

CHOOSING THE SYSTEM FOR YOUR HOME

Some factors involved in choosing the type of solar retrofit for your home include the style, layout and location of your home; the amount of money you want to spend; zoning and building codes; and how much involvement you want to have with your system.

Direct gain systems are probably the least costly of the three options. They generally are not governed by zoning ordinances and can usually provide significant heat to your home during the daytime. On the other hand, adding direct gain windows may reduce privacy, especially if bedrooms or baths are located on the south side, and they can increase summer air conditioning bills. Nighttime heat loss through the large window areas also can be a problem, but movable insulation (either thermal drapes or shutters) can be used over the windows at night to retain heat.

The Trombe wall probably requires the least effort to operate of all the passive systems and is ideal for living spaces where quiet and privacy are desired. Since it provides most of its heat to the living space during the evening and nighttime hours, it is ideal for use in bedrooms. You should, however, provide for some method of cleaning the interior area between the glazing and the storage portion of a Trombe wall. Like direct gain systems, Trombe walls are not normally affected by zoning ordinances.

Sunspaces are very popular passive retrofits because they can expand the living area of a house. However, zoning setback requirements may affect the construction of an addition on the south side of your house. Nighttime heat loss is not as critical in the sunspace as with direct gain systems since it can be closed off from the house. However, night insulation is recommended if the sunspace serves as living space after sundown.

THE NEXT STEP

Once you decide that a solar retrofit will work for you, the next step is to decide how much personal involvement to have in the design and construction of the system. If you have a design in mind and are handy with tools, you may want to handle the entire project by yourself. Before you try, a word of caution: know what you're doing. Not only could you build a system that doesn't work, but you could also violate zoning or building codes or structurally damage your home. Consult accepted publications and experienced professionals before you begin.

ADDITIONAL SOURCES OF INFORMATION

Mazria, E. *The Passive Solar Energy Book*. Emmaus, Pennsylvania: Rodale Press, 1970.

Southern Solar Energy Center. *Passive Retrofit Handbook*. Atlanta, Ga: Southern Solar Energy Center, 1980. To be available from the Technical Information Center, U.S. Department of Energy, P.O. Box 62, Oak Ridge, TN 37830.

TECHNICAL BRIEF

DIRECT GAIN SYSTEMS

A direct gain system is the simplest application of passive solar heating. It involves south facing windows for collecting solar energy and thermal mass for heat storage. This* Technical Brief *describes the basic function of direct gain systems and provides some simplified design and sizing guidelines.

HOW DIRECT GAIN SYSTEMS WORK

Direct gain systems use south-facing windows to capture heat from the winter sun. Sunlight passes through the glass, strikes the interior surfaces of the room, and warms them. As these surfaces warm up, they radiate heat, warming the air and objects in the room.

Direct gain systems normally include thermal mass materials that have the capacity to absorb and store solar energy. These materials can be brick, rock, tile, concrete, or water. Thermal mass stores heat when the sun is shining and releases the heat when the room temperature falls at night and during cloudy periods. Mass also prevents daytime overheating by absorbing excess heat. *(See Figure 1.)* Thermal mass materials can take the form of many common structural elements: a brick fireplace, a stone wall, or a tile floor. *(See Figure 2.)*

Heat produced by the direct gain system can be distributed throughout the home by fans or natural circulation. Open floor plans also facilitate heat distribution.

THE WINDOW

The window is the key component of the direct gain system. The direct gain window is normally a standard window or patio door installed in a south facing wall. The vertical glazing of a standard window offers the best combination of winter heat gain and ease of summer shading. It is also easy to install and is less prone to water leaks or breakage than sloped glass.

There are times when a large expanse of vertical glazing at ground level is impractical. When the southern exposure is obstructed by nearby structures or when privacy is a concern on the south side of the house, a ground-level wall of vertical windows may not be practical. Large window areas also create glare problems and can cause fading of objects in the room.

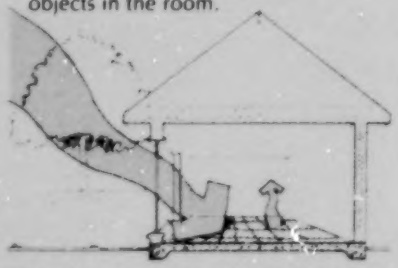


Figure 1. Basic configuration of a direct gain system with a tile floor for thermal storage mass.

These conditions do not necessarily preclude the use of a direct gain system. In such cases, glass can be installed in the roof in the form of clerestory windows *(see Figure 3)*. With roof-level windows, nearby obstructions are not as likely to affect solar collection, and privacy is unaffected. Roof apertures are an effective way to reduce glare, because light entering a room from above doesn't create as much contrast between window and interior surfaces as a floor-level window does. Another advantage to roof-level glazing is that it allows more flexibility in the placement of thermal storage mass. The clerestory can be positioned so that it allows sunlight to strike a thermal mass element, such as a fireplace or a wall, that sunlight might not reach from vertical, floor-level windows.

A skylight, carefully placed to admit the low winter sun, can serve as the direct gain collector when vertical glazing is impractical. However, be aware that the inclined glazing in the skylight is more difficult to shade in the summer than vertical glazing.

Figure 2. A room using a brick wall and tile floor as massive elements in a direct gain system.

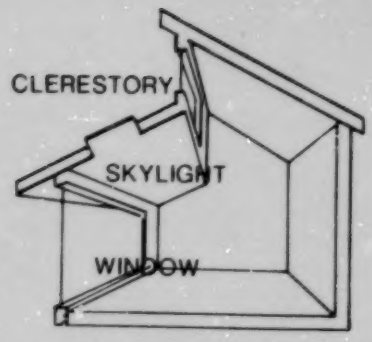


Figure 3. Types of direct gain windows.

Orientation

The optimum orientation for direct gain glass is due south. However, deviations of up to 15 degrees from due south can still produce useful solar heating. Orientation of more than 15 degrees will reduce winter heat gains and may cause overheating during the summer from east and west exposures. To be an effective source of winter heating, direct gain glass should be exposed directly to the sun for at least four hours between 9:00 a.m. to 3:00 p.m.

Sizing

There is no one simple guideline for calculating the amount of glass area to be used in a direct gain system. The local climate, the size of the home, and the home's energy efficiency are three of the most important determining factors.

The maps in Figure 4 show the size of glazing required to achieve a solar savings fraction ranging from 20 to 50 percent for a 1,500 square foot ranch style home in the South. (The Solar Savings Fraction (SSF) is an indication of the relative savings in heating energy produced by a direct gain system). The hypothetical home is built on a concrete slab with thick-edge or turn-down footing. Exterior wall insulation is rated at R-20, attic insulation at R-26, and perimeter insulation at R-5. Also, it is assumed that R-4 movable insulation is used on the direct gain glazing to prevent heat loss at night and on cloudy days. To reduce air infiltration, the entire house is wrapped with polyethylene and is thoroughly caulked and weatherstripped.

Note that in some areas a direct gain system with an SSF of more than 20 to 30 percent is not recommended. This is because the heating energy saved by the direct gain system during winter in these locations is offset by the additional cooling load caused by the system in summer.

In other areas, where the glazing required for the desired SSF would be more than 300 square feet, it would be difficult to add sufficient thermal mass in the hypothetical 1,500 square foot house to absorb all the heat produced by the direct gain system. Consequently, the direct gain system would cause overheating problems during winter in the house used in the example. Winter overheating problems can be prevented in homes of this size if they are specifically constructed to accommodate the proper amount of thermal mass for a large direct gain system.

For a general estimate of the direct gain glazing area for your house, find your location on the maps. This will give you a range of the area of glazing required. Remember that these figures were calculated for a specific house with high levels of insulation and weatherization. Since there is no simple formula for sizing direct gain glazing for all houses, you should obtain the assistance of a design professional experienced in passive solar design for calculating the exact amount of glass you will need for your house.

Direct gain systems are an integrated part of the home, so they can't be shut off. Therefore, large systems should be approached with caution. Improper sizing can result in overheating, even in winter. Generally, a direct gain system with an SSF greater than 50 percent is not practical in the South because of the increased cooling load caused by the system or the excessive amount of thermal mass required for very large glass areas.

Materials

The energy performance of different types of windows varies in terms of infiltration and heat loss. Double glazed windows are recommended for direct gain systems to reduce heat loss. The frame of a window can also affect its performance by as much as 25 percent. The infiltration rate for a casement or awning window, in which the joints are sealed by compression, is higher than that of a fixed window with no operable joints but lower than that of a single or double hung window, which has a sliding type seal. Also, the good insulating qualities of wood make it the optimum frame for cutting heat loss. When using a metal frame window, be certain that it has a thermal break to reduce heat losses through the frame.

THERMAL STORAGE MASS

As mentioned earlier, thermal mass enhances the performance of direct gain systems. It absorbs heat when the temperature of the air is higher than the temperature of the mass. When the surrounding temperature is lower – at night and during cloudy periods – the mass releases its heat to the room. Mass also helps prevent room air from overheating. In fact, direct gain systems with more than a 25 percent SSF usually require additional thermal storage mass considerations to prevent winter overheating problems.

Thermal Mass Techniques

Floors, walls, and room elements function as thermal storage mass. A concrete floor covered with tile is an excellent storage medium if care is taken not to cover much of it with carpet or rugs (this reduces its storage capability). Wood-frame floors can be converted to storage mass floors by adding tile, stone, or lightweight concrete that is at least 2 inches thick, but caution must be observed to ensure that the floor joists have the structural capacity to carry the additional load.

An interior masonry wall or fireplace can also serve as the thermal mass for a direct gain system. The low winter sun can either shine directly on the wall if it is near enough to the window, or if the wall is set back into the space, a light colored floor surface in the foreground can reflect indirect radiation to the wall. Clerestory windows and skylights, as previously discussed, are a good way to direct sunlight to a massive element.

such as a stone fireplace, that may be too far from floor-level windows for the sun to reach it.

Thermal mass can be supplied by several elements which together provide the total mass required. For instance, a floor covered with tile adjacent to a wall faced with brick might provide the necessary amount of thermal storage for the window size.

Water can also provide thermal mass. It is a very dense substance and can store a great deal of heat for its volume. It is also quite inexpensive apart from the cost of the container. Water storage may be objectionable to some people because of the difficulty of blending water drums into the decor. However, many water containers are being developed and marketed now that are more aesthetically acceptable. There are also ways that the drums can be covered with translucent plastic materials or hidden by a bench or wall, making their appearance less objectionable and providing additional insulation.

Phase change materials are another medium for storing heat. These materials are chemical compounds that melt and change from a solid to a liquid at around 80°F. As they melt, they absorb a great deal of energy. When they cool down and begin to solidify, they release the stored energy as heat. Phase change materials can hold up to five times the heat as an equivalent volume of water, but their higher cost may make them prohibitive unless space is at a premium.

Sizing

A simple rule of thumb for sizing the amount of thermal mass required for a direct gain system is four gallons of water or 150 pounds of masonry for each square foot of glass. For example, a direct gain system with 100 square feet of glazing would require 400 gallons of water or 15,000 pounds of masonry for thermal storage mass. It should be noted that for direct gain systems with a low SSF (20 percent), additional thermal mass is probably not needed in a conventional slab-on-grade home as long as much of the concrete floor is finished with tile or linoleum, which along with conventional sheetrock walls and ceiling, will provide sufficient mass.

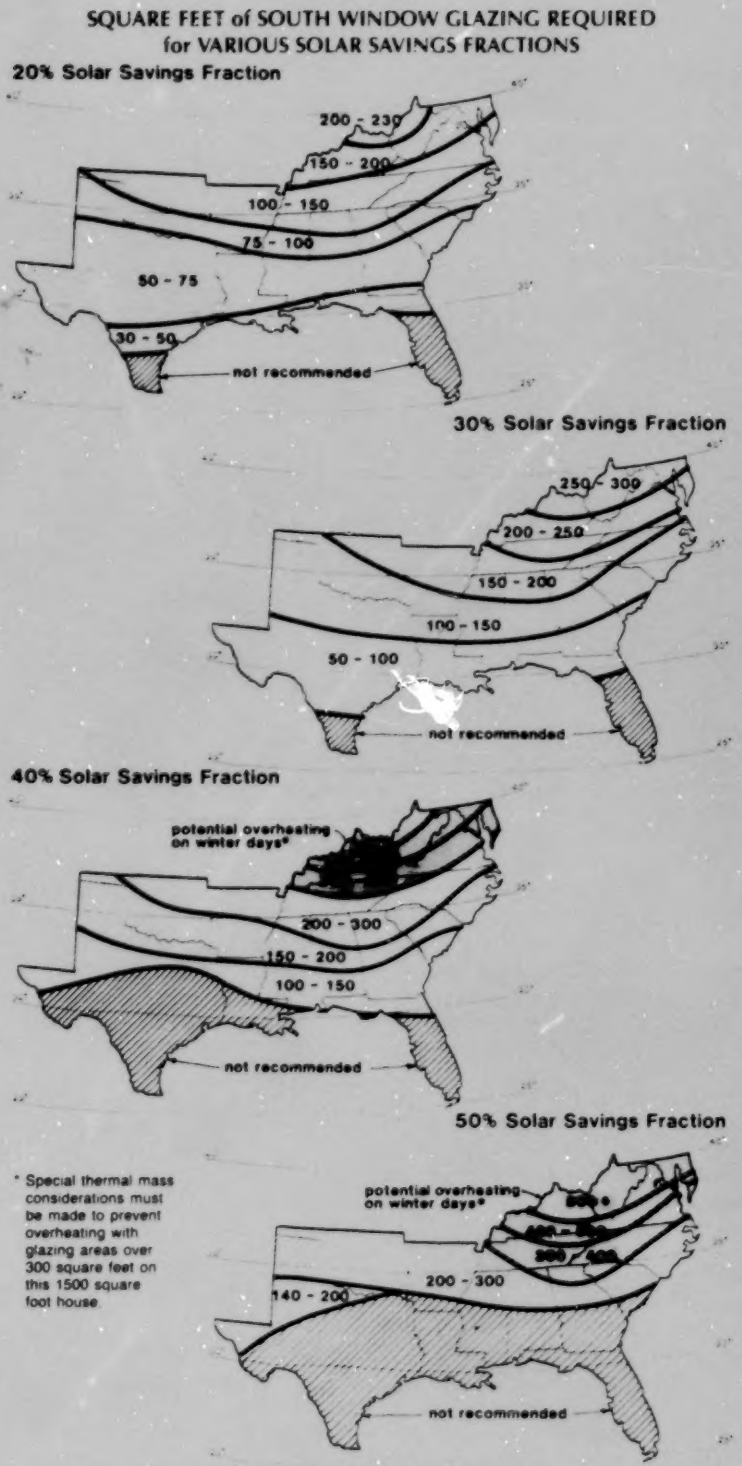

SQUARE FEET of SOUTH WINDOW GLAZING REQUIRED
for VARIOUS SOLAR SAVINGS FRACTIONS
20% Solar Savings Fraction
200 - 230
150 - 200
100 - 150
75 - 100
50 - 75
30 - 50
not recommended
30% Solar Savings Fraction
250 - 300
200 - 250
150 - 200
100 - 150
50 - 100
not recommended
40% Solar Savings Fraction
potential overheating on winter days*
200 - 300
150 - 200
100 - 150
not recommended
50% Solar Savings Fraction
potential overheating on winter days*
200 - 300
140 - 200
not recommended
* Special thermal mass considerations must be made to prevent overheating with glazing areas over 300 square feet on this 1500 square foot house.

Figure 4. Solar Savings Fractions.

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Additional points to remember when designing the thermal storage mass are:

To work effectively, mass should be entirely within the rooms with direct gain windows.

The exposed surface of the mass should be at least three times the glass area.

Masonry storage is only effective to a depth of 4 to 6 inches, so additional thickness in floor slab or walls is of little benefit.

Floor coverings, such as carpet and rugs, will reduce the effectiveness of the thermal mass.

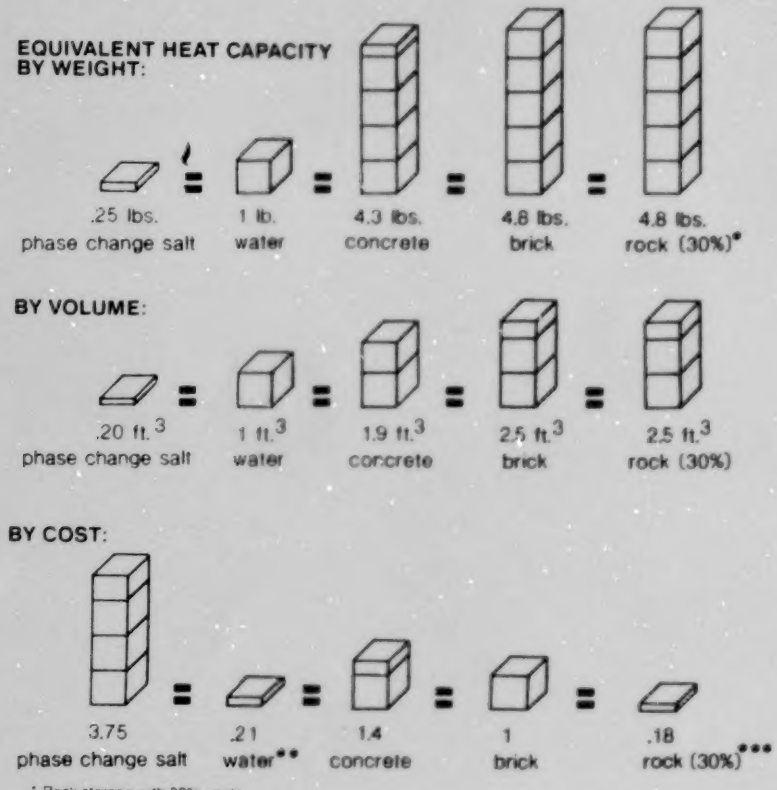
Materials

Figure 5 compares various thermal storage materials in terms of their heat storage capacity by weight, volume, and cost. As the figure shows, one pound of water will store the same amount of heat as 4.3 pounds of concrete or 4.8 pounds of brick. Water also takes up less space. A cubic foot of water has the same heat storage capacity as 1.9 cubic feet of concrete or 2.5 cubic feet of brick.

The cost data in the comparison is the relative cost-per-unit of storage based on brick equal to 1. For example, a concrete storage system will cost 1.4 times more than a brick storage system that will store the same amount of energy.

Figure 5.

COMPARISON of THERMAL STORAGE MATERIALS



* Rock storage with 30% voids
** Based on 55 gallon drum storage container
*** Cost is for material only

NIGHT INSULATION AND SHADING

Movable insulation should be used to reduce nighttime heat loss from direct gain windows during winter. This can take the form of rigid panels or insulated drapes or shades. The latter are more popular because they are easier to use. Night insulation can increase heat production from the direct gain system by as much as 50 percent. A minimum of R-4 insulation is recommended for heat loss reduction.

To prevent the direct gain system from increasing summer air conditioning loads, shading of one or several types must be employed. A roof overhang, carefully sized to admit low winter sun but block the high summer sun, can be used. The overhang will block only direct radiation, so an additional form of shading, such as blinds or shades, is necessary to block diffused or indirect sunlight. (Indirect solar radiation usually accounts for 60 to 80 percent of the total summer solar radiation entering the window.) Exterior shading is much more effective than interior shading because it blocks the solar radiation before it enters the home. Several types of weatherproof shades and blinds are available for this purpose.

Deciduous trees or vines can also be used to shade a direct gain system in summer.

A direct gain system can meet a significant portion of a home's heating requirements if the system is tailored to the individual house and climate. It is important to remember that a direct gain system is part of a home's living space. So if improper sizing causes overheating, you will have to live with it or rebuild it. Although a direct gain system may not be the best choice for every home or climate, if properly designed and sized, it can be a relatively simple and effective application of passive solar space heating.

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TECHNICAL BRIEF
BATCH WATER HEATERS

Batch water heaters — also called breadbox or integral water heaters — are gaining popularity as low-cost solar hot water systems. These simple passive water heaters involve no mechanical components, have long life spans, and can be built from scratch by anyone with basic handyman skills. This Technical Brief describes characteristics of batch systems and their components.

A batch water heater is a passive solar system that uses the sun's energy directly to heat water. It requires no rooftop collector, pump, or special plumbing. In its simplest and most common form it consists of a water tank that has been painted black to increase heat absorption and enclosed in a box that is covered with glass or a synthetic glazing. The box is oriented to face due south, and the tank inside the box is tilted at an angle that provides optimum solar exposure (the angle of tilt is usually equivalent to the latitude of the site). The tank or tanks are connected to the existing household hot water system. Cold water enters the batch heater from the outside supply, is heated by the sun, and then flows into the home's water heater under normal household water pressure. The batch heater's function is to preheat the water supplied to the conventional water heater, which, as a result, consumes less energy. Depending on the amount of solar radiation, the water supplied by the batch heater can be anywhere from a few degrees above the intake temperature to above the conventional water heater's thermostat setting.

PERFORMANCE AND COST

Simplicity and economy make batch water heaters an appealing way to use solar energy. They involve no mechanical parts to break down and require repairs, and components and construction requirements are relatively uncomplicated. Batch water heaters can be built for a materials cost of only a few hundred dollars, making them the least expensive of solar heating systems. Based on various performance claims, they can reduce the energy consumed for water heating by anywhere from 25 to 50 percent. Ready-made batch systems of varying levels of sophistication are becoming increasingly available and can be purchased for prices ranging from $1,000 to $2,500 dollars. Many manufacturers of these ready-made systems claim their systems reduce hot water costs by 60 to 85 percent.

There is little data to quantify performance of batch systems. Most of the studies that have been done so far offer data for one particular type of system under a given set of circumstances. No generalizations can be made that might indicate precisely what performance can be expected. What little data is available suggests that batch systems, as a group, are the least efficient performers in the family of solar water heaters. However, the low cost of home-built systems can make them pay for themselves in energy savings in a shorter time period than other solar water heaters.

LOCATION AND ORIENTATION

The majority of batch systems are located at ground level. Siting follows the rules of any passive solar system: the glazing should face as close to due south as possible, but variations of up to 20 degrees east or west will not affect performance to a significant degree.

The glazing of the batch system should receive unimpeded sunlight from 9 a.m. to 3 p.m., so potential sources of shade should be avoided in siting the system. A roof overhang that does not block the low winter sun may block the high summer sun. In the winter, deciduous trees may not be a problem, but their foliage may block the sunlight in summer.

When shading is a problem or if a due south orientation is blocked, the roof may be considered as a location for the batch heater. Some manufactured models are actually designed for rooftop use. Structural support is extremely important in rooftop mounting, since the water in a 38 gallon tank will weigh over 350 pounds. Therefore, it is essential that roof construction be evaluated carefully before a roof mounting is attempted.

The batch system should be positioned as close to the home's conventional water heater as possible. This simplifies plumbing work and reduces heat loss from pipes running between the two systems.

COMPONENTS AND SIZING

Quality materials will ensure a long life span for a batch system. These systems require virtually no maintenance since they have no moving parts, so the only limiting factor in the life of the system will be the durability of the components. A system with high quality components can have a useful life of 10 to 15 years.

Tanks

The basic component of the batch system is the tank. There are various types of tanks available ranging from stainless steel to plastic. Cost, and in some cases weight, are the guiding considerations in selecting the material. Many home-built systems employ standard water heater

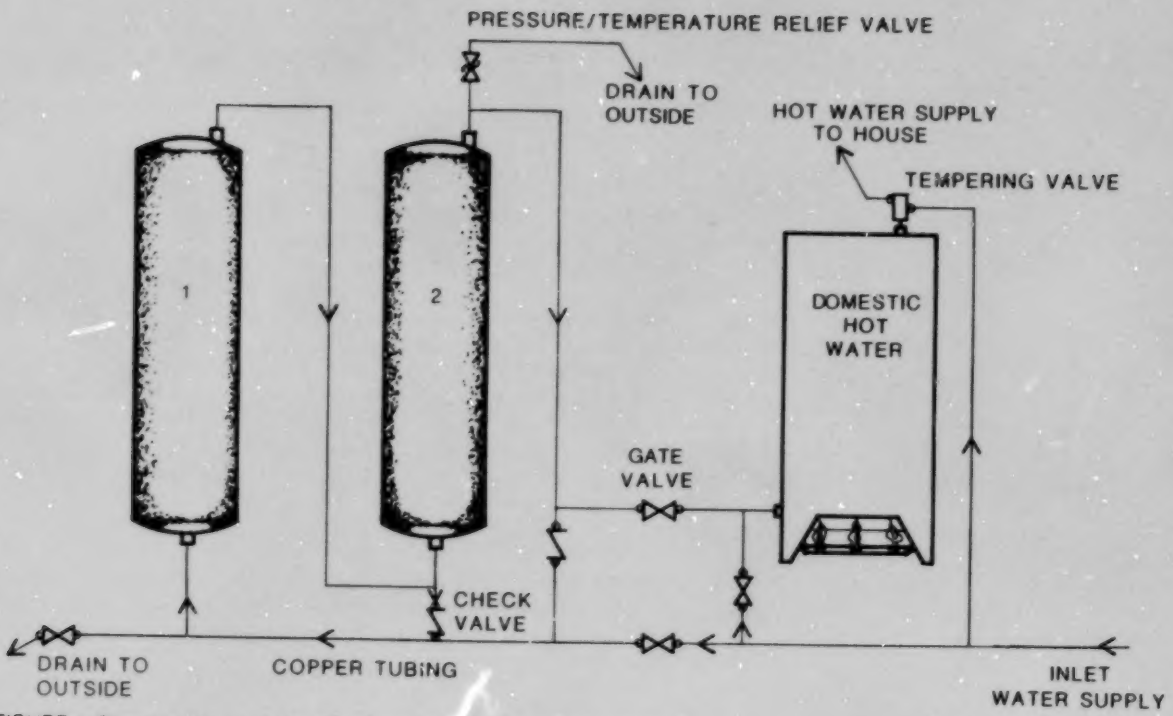

FIGURE 1. Plumbing Schematic For Two-Tank Batch System Piped in Series.

tanks (minus the insulated exterior), which are available as salvage items at a nominal cost.

There are few if any rules of thumb for sizing a batch system for a particular household. Some manufacturers offer guidelines for water volume of batch heaters in relationship to family size – roughly a 30-gallon tank for two people. Others maintain that there are no good sizing criteria for batch systems, since these are really preheaters. Until definitive data is available, the purchaser or builder of a batch system must rely on the designer or manufacturer's recommendations.

Many designers base the volume of their systems on considerations other than the number of people in the household. Two-tank systems may be selected, not to increase water volume, but to increase the temperature of the preheated water. In a one-tank system, warm water flows out from the top of the tank to the conventional water heater and is replaced by cold water, which flows into the bottom of the tank from the outside supply. This cold water reduces the overall temperature in the tank and thus, the temperature of the water reaching the home's water heater. In two-tank systems, warm water flows from the top of tank #1 to the bottom of tank #2 (see Figure 1). There it is heated, causing it to rise and flow from tank #2 to the house. Thus, the water in tank #2 is warmer than that in tank #1, and the temperature of the water fed into the household system is higher. Spreading the water between two tanks also increases the surface area exposed to the sun, which increases solar collection.

A vertical rather than horizontal configuration is usually the best one for the water tank. This is because there is more room for temperature stratification along the 70-inch length of the tank than in the 10-to-20 inch width. In two-tank systems the tanks can be placed vertically side by side and piped in series or in parallel, series producing the higher water temperature.

Glazing

Glazing material is a matter of preference, but durability, ease of use, and good transmittance qualities make a twin-wall polycarbonate glazing a good choice. It is lightweight and, consequently, easy to handle. Most polycarbonates are reasonably efficient in transmitting solar radiation and they are less expensive than tempered glass. If the builder elects to use glass, it should be of a tempered type, such as that used in patio doors, to minimize the possibility of breakage. Tempered glass cannot be cut, so the batch system design will be limited to the configuration of available sizes.

There are more definite sizing guidelines for the ratio of glass area to water volume. The objective in sizing glazing is to increase solar gain as much as possible while keeping heat loss to a minimum. Too little glazing will reduce solar gain, but too much will allow heat loss. The point at which these two factors balance out is approximately the ratio of two gallons of water to one square foot of glazing.

THE BOX

The housing for the water tanks in

home-built batch systems is usually a triangular wooden box that is insulated to inhibit heat loss. To further enhance solar collection, the box that holds the tank is usually lined with a reflective material, such as mylar or aluminum foil, to reflect sunlight striking the back and sides of the box onto the tanks. (Figure 2 provides a diagram of a typical home-built batch system.) Some designs take this idea a step further and employ curved surfaces inside the box to increase reflectance. Manufactured systems employ various housings in shapes and sizes that range from cylinders to shallow rectangular boxes resembling flat-plate solar collectors.

FREEZE PROTECTION

Most solar water heaters must employ some method for dealing with freezing temperatures. In most of the Sun Belt states, freezing is not much of a problem for batch water heaters because the mass of the water itself generally retains enough heat to keep tanks above freezing temperatures. However, any plumbing outside the box is subject to freezing and must be protected. If circumstances permit the builder to construct the box over the plumbing so that it is enclosed, then the likelihood of pipes freezing is reduced.

Many designs call for double or triple glazing which further increases resistance to freezing because of the added insulation value. There are tradeoffs between the reduction in absorbed solar energy caused by double and triple glazing and its heat retention or insulation value. Many designers recommend that a layer of glass be used internally with one or more layers of plastic as outer covers to provide maximum efficiency.

To further increase heat retention and reduce the likelihood of freezing, the box that holds the tank also is insulated with R-11 batt or rigid insulation. As a further precaution, a panel of movable R-7 insulation may be used over the glazing at night. This is often worked into the system design as doors that must be opened during the day and shut at night. Night insulation can be a problem because the system user has to remember to apply it and to remove it in the morning. If the glazing remains covered during the day, the system doesn't function. If it is uncovered at night, the tanks lose heat rapidly.

In areas where freezing temperatures occur regularly, the batch system can be drained for the three or four months of very cold weather. These are usually months where the performance of the system will be impaired by cold ambient temperatures anyway, so its value as a water preheater during this period will be only marginal.

Many manufacturers and designers provide freeze protection with a combination of triple glazing and something called a selective surface. A selective surface is a special coating, such as black nickel chrome, that is applied to the tank. It increases heat absorption from solar energy but reradiates very little of the heat. These materials are relatively expensive, and their effectiveness in batch systems is considered questionable by some designers, since they may not increase heat production sufficiently to justify their cost. Here again, there is little data to make a case either way.

Since no definitive study has been completed that measures performance of batch solar water heaters or compares them to other systems, they must be judged on their own merits. Their principal appeal is low cost and ease of construction. They can be built from common materials, and because they are so uncomplicated, even a novice handyman can assemble one. As a do-it-yourself option, a batch water heater is relatively inexpensive – it can be built for under $800. This means it can pay for itself a lot faster than other solar water heaters, which range in price from $1,500 to $4,000. And even a do-it-yourself batch solar water heater qualifies for the 40 percent solar tax credit. Manufactured batch systems, which are becoming more and more available, range in price from about $1,000 to $2,500 depending on system and manufacturer.

Much remains to be learned about batch system performance and the economics of these systems. In the absence of real data, the only "performance evaluation" that can be cited is that many who rely on batch systems for a portion of their hot water supply report good performance and consider them a good investment.

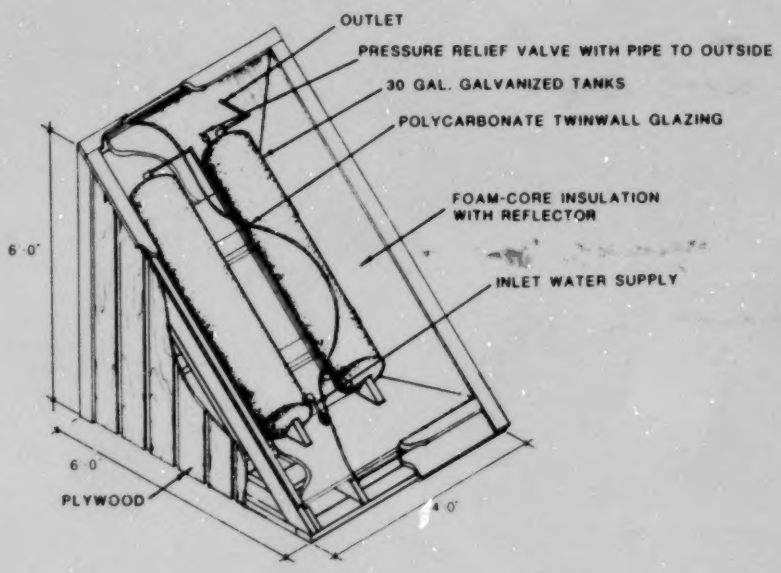

FIGURE 2. Cutaway View of Typical Home-Built Batch Water Heater.

OVERALL SYSTEM EFFICIENCY

A preliminary step to adding a batch water heater or any other solar water heater is an assessment of the overall energy efficiency of the household water heating system. Water tanks located in unconditioned spaces, such as a basement or crawl space, should be wrapped with R-16 insulation with foil backing (the foil should face outward). The temperature and pressure-relief valves, electric junction box, and the supply cable to the heater should not be covered. In gas water heaters it is important not to place insulation too close to the flue. The local gas utility should be consulted for insulation guidelines as a safety precaution. Pipes running from the water heater to supply outlets throughout the house should be insulated. In electric water heaters an automatic timer may be attached to the heating element to operate the heater only during periods when household activities require hot water. Flow-restricting shower heads and faucet aerators reduce hot water consumption.

A typical system retrofit, including insulation, timer, and shower heads, can be done for under $100. This can be paid back in resultant savings in the first year if the heat source is electricity and in a slightly longer period for gas water heaters.

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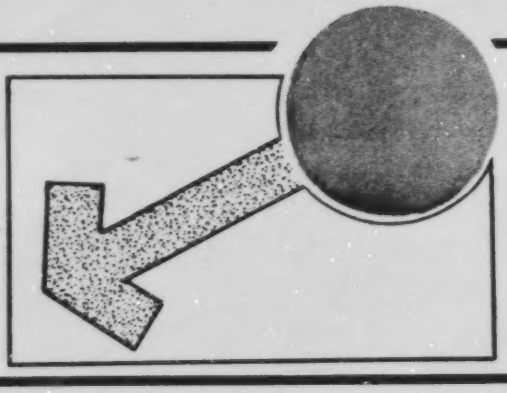
Solar Retrofit Guide



A NEW DESIGN

Considering that previous batch solar water heater designs required custom glazing, I designed a batch water heater that uses a standard tempered glass panel (34" x 76") as the primary component. This glass panel is the main element in the design, around which all other parts are built because:

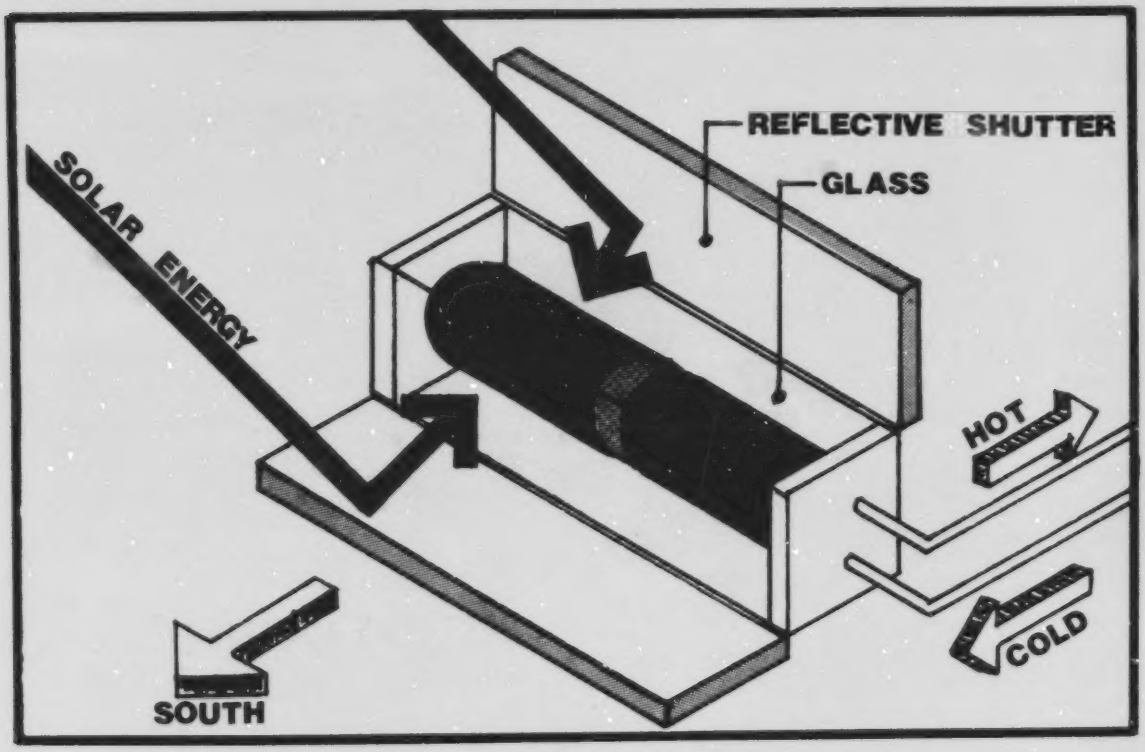
1) It is kept in stock as a standard replacement for sliding glass doors and can be bought locally throughout Arkansas. $20-29 for single pane or $60-65 for double pane.

2) It is long enough and wide enough to enclose two typical recycled gas or electric water heater tanks.

3) It will not degrade under sunlight.

4) It has a very high impact strength to resist damage by hail and other objects.

(Extracted from *Arkansas Solar Retrofit Guide* available from the Arkansas Energy Office.)



ENERGY FACT SHEET

EARTH SHELTERED HOUSES

A properly designed earth sheltered house can provide significant energy savings to the homeowner. The earth cover serves to moderate outside temperature effects on a home so that its heating and cooling needs are reduced. This Energy Fact Sheet summarizes the advantages of earth sheltered housing as well as certain factors that require special consideration in earth sheltered construction.

WHY BUILD AN EARTH SHELTERED HOUSE?

A principal advantage of an earth sheltered house is energy savings. An above-ground house suffers energy loss through its walls and roof, which are exposed to daily and seasonal fluctuations in outside air temperature. However, these temperature fluctuations are felt much less below grade. Energy loss from air infiltration is also much lower in earth sheltered houses. The earth's mass around an earth sheltered building increases its heat storage capacity, enabling it to maintain fairly constant or slowly changing inside temperatures. This helps keep a home comfortable and protects the plumbing from freezing, even during power outages. Since the earth's mass will minimize inside temperature swings, the house can function well in winter with a passive solar space heating system or a wood burning stove.

Apart from energy savings, a well designed earth sheltered building entails lower maintenance costs. An earth covered roof won't need new shingles and exterior walls won't need painting. Noise levels also are low so that an earth sheltered house can be built on a busy city street or adjacent to an expressway without sacrificing quiet.

TYPES OF EARTH SHELTERED HOUSES

Earth sheltering is a general concept and not one type of design. Site characteristics, space requirements, and aesthetics influence the shape and style of the earth sheltered house. In general terms, any house whose roof and walls are covered fifty percent or more with earth is earth sheltered. The relationship of the house to the ground surface can vary widely. In fact, an earth sheltered house is not necessarily below the natural ground level (*see Figure 1*).

There are also variations in the areas covered and the amount of earth covering the floors and walls. Some earth sheltered houses have bermed walls and a conventional roof. Others are completely covered with only window and door openings exposed. The covering itself can range from several inches to several feet of earth.

Structural systems also differ in response to the type and amount of earth used. Structural systems include poured concrete, concrete block, precast concrete, pressure-treated wood, steel highway culverts, and thin-shelled concrete designs. Figure 2 illustrates some common styles of earth sheltered houses.

SPECIAL CONSIDERATIONS

Earth sheltered housing is relatively new to residential construction, especially in the South. Construction details may be unfamiliar to residential builders, though the materials and techniques have been employed in commercial buildings for years. There may also be institutional barriers relating to building codes, zoning ordinances, and restrictive covenants.

Construction Details

Construction details can vary widely with locale because of variations in humidity, soil types, ground water levels, and heating and cooling requirements. Thus, it is important to work with a building professional with local experience in constructing earth sheltered

Figure 1. An above grade earth sheltered house

houses. Finding such a person may be the first challenge in building an earth sheltered house. A local chapter of the American Institute of Architects is a possible source of information, or a local solar energy association may be able to furnish names of professionals experienced in earth sheltered housing.

Many of the existing earth sheltered houses were do-it-yourself projects. Several references are offered at the end of this Energy Fact Sheet to provide information to those interested in building their own earth sheltered house. However, be advised that maneuvering tons of earth and supporting that earth with walls and roof requires a sound knowledge of soil characteristics, structural engineering, and construction practices. So if you are interested in doing it yourself, you can minimize the risks by procuring professional services for certain strategic steps. A soil test of the site should be ordered from a testing firm to determine load-bearing capacity and possible settlements that may occur. A structural engineer can be retained to evaluate the building design and certify its structural soundness.

The biggest potential problem area in earth sheltered construction is waterproofing. Not only is waterproofing more complicated in an earth sheltered than a conventional house, if it doesn't work, correcting a problem involves moving the earth cover to get at the leak and risking structural shifts as stresses change with earth movement. For this reason, even if you decide to build the house yourself, it is important to get advice from someone who knows how to waterproof, someone with a knowledge of materials and an understanding of which ones will work in your locale.

Not only must the builder know what waterproofing materials to use, but how to use them. Work should be closely supervised to assure that correct installation procedures are followed in laying the material and to catch any damage that may occur to it during construction so that it can be remedied before the earth mass is moved into place. Special care must be taken to protect the waterproofing from damage during backfilling.

The possibility of condensation on walls in summer from increased interior humidity levels is another area of special concern in earth sheltered construction. The use of exterior wall insulation will prevent the walls from cooling down to earth temperatures, thus reducing condensation problems. However, exterior insulation will also reduce the summer cooling effect of earth-backed walls. Mechanical air conditioning can solve the humidity problem. Closets and other closed spaces adjacent to earth sheltered walls should be vented.

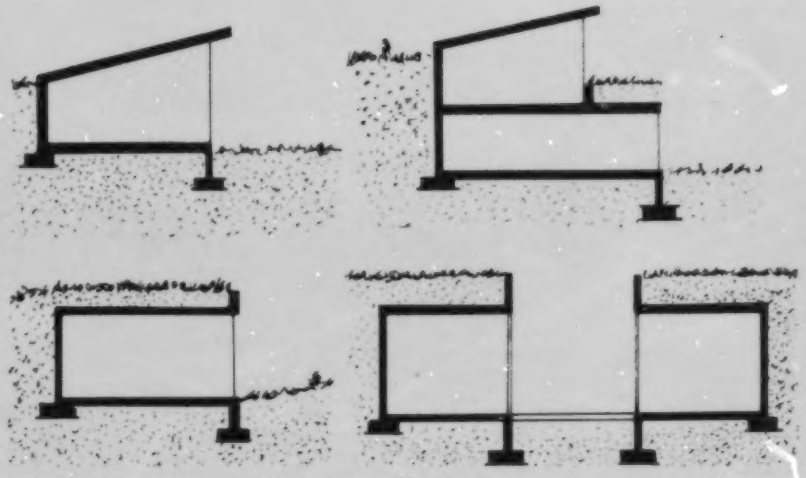


Figure 2. Common types of earth sheltered houses.

Institutional Barriers

A home's conformance with ***building codes*** often depends on a local official's interpretation, and with earth sheltered design there are some areas of potential difficulty. Most codes have prescriptive standards relating to the size of windows in each room. Also, codes usually require an operable window or door in each sleeping room to provide egress to the outside in case of fire. Other potential areas of difficulty are roofing specifications and insulation requirements where earth may or may not be considered an acceptable substitute for materials specified.

Zoning ordinances regulate the type, size, and location of buildings in order to separate incompatible uses of land and to preserve the character of neighborhoods. Such ordinances can vary widely, but possible problem areas for earth sheltered houses are minimum above ground floor-space requirements (so-called "basement ordinances") and set-back requirements.

Restrictive convenants are regulations devised by the architect or developer of a community that govern the use of lots within that development. As with building codes and zoning, these regulations primarily affect urban and suburban construction. Plans for a house within a community governed by such covenants may have to be submitted to an architectural review committee or a similar body for approval prior to construction. Covenants present a special problem because they are private agreements and thus are not subject to a variance process as are codes and zoning ordinances.

As with most design innovations, building an earth sheltered house has its own special challenges. However, careful planning and sound, professional construction practices can make an earth sheltered home an attractive, energy-saving option for the homeowner.

Additional information on earth sheltered construction is available from the following sources:

Roy, Robert L. *Underground Houses: How to Build a Low-Cost Home*. New York: Sterling Publishing Co., 1979.

Underground Space Center. *Earth Sheltered Housing Design*. New York: Van Nostrand Reinhold Company, 1978.

Wells, Malcolm. *Underground Designs*. Brewster, MA: Malcolm Wells, 1977.

TECHNICAL BRIEF

THERMAL ENVELOPE HOUSES

The concept of the thermal envelope house, also called a double envelope house, was introduced several years ago as a way to reduce a home's heating and cooling requirements. The design has gained popularity in many areas of the country; however, the dynamics of air flow and heat transfer within the thermal envelope has been the subject of controversy. Experience has shown that thermal envelope homes do indeed use substantially less energy than conventional homes although the thermal envelope does not necessarily function as suggested by some designers. This Technical Brief describes the basic thermal envelope design and operational characteristics and summarizes the results of a performance monitoring study of a thermal envelope house.

BASIC DESIGN

The basic thermal envelope design is essentially a house within a house. It is characterized by two insulating envelopes, one within the other. A continuous air space is formed between the two envelopes that allows air to circulate unimpeded in a loop through four areas. These four areas include a sunspace on the south side of the house, an attic cavity, an air cavity between two north walls, and a plenum underneath the slab connecting the loop to the earth. This continuous air loop is thermally insulated from the outside as well as the core interior of the house. Figure 1 shows the sunspace area of a thermal envelope house. Vents are located along the ceiling and floor, connecting the sunspace to the thermal envelope loop.

The presence of the air space and two insulated envelopes creates a very well-insulated and air-tight house. In fact, it has been found that thermal envelope homes perform in much the same way as superinsulated structures. The substantial insulation effect of the thermal envelope combined with the solar heat gains produced by the sunspace can certainly reduce a home's heating requirements. However, actual operating dynamics of the thermal envelope, in terms of air flow and heat transfer in the loop, has caused much debate.

OPERATIONAL CHARACTERISTICS

The original concept, introduced by California architect Lee Porter Butler in the early 1970s, showed the winter daytime operation of the thermal envelope as it is depicted in Figure 2. The air would gain heat in the sunspace and rise to the attic because of natural thermal convection. Air in the north wall cavity would lose heat to the cooler walls and thus flow downward to the crawlspace plenum. This air movement would induce a pressure gradient which would pull the warm air from the attic to the crawlspace plenum where excess heat would be stored in the earth mass. The cooled air would then flow into the sunspace to regain heat and continue the cycle.

It was postulated that at night the cycle in the air loop would reverse direction (see Figure 3). Air would be cooled from outward heat flow through the glass in the sunspace. This would then draw heat that was stored in the earth mass during the day into the thermal envelope loop to moderate interior temperatures at night.

In the summer, the hot air would be exhausted from a vent at the top of the sunspace, drawing cool air from the earth plenum into the loop. Many envelope designs also employ earth cooling tubes in order to enhance the cooling effect of the crawlspace plenum. (Earth cooling tubes draw warm outside air through underground tubes where the air's heat is transferred to the earth before it reaches the house.) The cooler air in the thermal envelope would serve as a buffer between the interior and hot outside temperatures. Also, the outer shell of the envelope would shade the inner envelope from direct solar gain, thus further reducing the home's air conditioning requirements.

Homes based on the thermal envelope design have been built in many areas of the country. Overall, these homes have performed well, with very low heating and cooling loads. However, the proposed air flow and heat transfer in the thermal envelope has been ques-

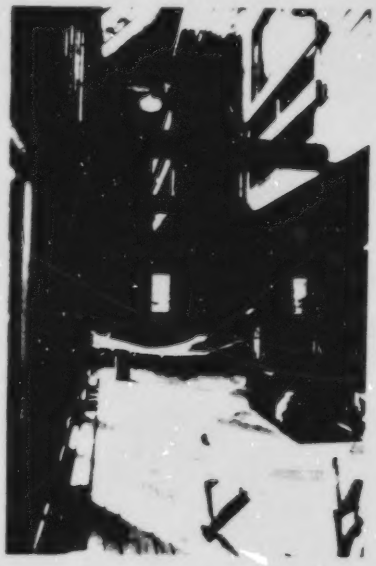


Figure 1. The sunspace is part of a continuous air loop in a thermal envelope house.

tioned because of factors relating to the basic principles of thermodynamics.

For example, the large surface area of the envelope will cause much of the air's heat to be transferred out of the loop. And, since the temperature differential would be greater between the air space and the outdoors than between the air space and the interior, most of the heat transfer would be to the outside. The rate of air flow in the thermal envelope will also affect heat transfer in the loop. Since natural convection air flow is relatively weak, air movement in the loop will be slow, causing the air in the sunspace to reach very high temperatures. (Temperatures around 100°F have been measured at the top of the sunspace in thermal envelope homes.) These high temperatures will increase the temperature differential between the air space and outdoors, resulting in even greater heat losses. In several modified designs, fans are used to move the air in the envelope loop or a window is opened in the north wall to increase the temperature differential within the loop and drive the air flow.

Insufficient air flow will also reduce the heat storage potential of the earth mass. The air will tend to stratify in the crawlspace plenum with warmer air accumulating at the top of the crawlspace and a layer of colder air settling on the earth floor.

Thermal properties of the earth will also affect its performance as a heat storage medium in winter and a heat sink in summer. For example, small variations in the soil's moisture content will have a major impact on its thermal conductivity – the capability of the soil to absorb and release heat. Generally, low moisture content will reduce conductivity, limiting the heat flow into the earth mass. Wide variations in soil properties will occur within the same geographic area and even within the same site. Thus, it is nearly impossible to predict how well earth storage will perform.

These factors – high heat losses, low air flow, and variable soil thermal properties – generally argue against the theory that the envelope loop will actually deliver heat to the interior or that the earth will store sufficient heat during the day to warm the air and drive the air flow in a reverse direction at night. The earth contact probably does have a tempering effect on the air in the large sunspace – helping to prevent overheating during the day and freezing at night. However, it has been suggested that another type of thermal storage system, such as a fan-forced system using masonry or rockbed storage, would be more effective than the earth in preventing temperature extremes in the sunspace.

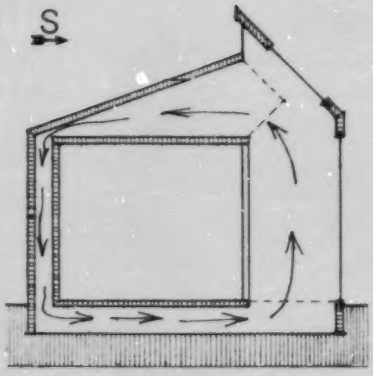


Figure 2. Winter daytime air flow.

Other concerns about the basic thermal envelope design include the potential fire hazard created by the continuous envelope loop and excessive condensation on the glazing of the outer envelope, particularly on windows in the exterior north wall. On the other hand, there are special advantages of the thermal envelope design. These homes do conserve energy. And they can be bright and open because the buffer provided by the outer envelope sunspace enables a designer to incorporate large areas of windows in the interior envelope without a high heat loss penalty. Consequently, there is no need for window insulation to prevent excessive heat losses at night and on cloudy days. The need for adding large amounts of thermal mass to the home is also eliminated because of the moderating influence provided by connecting the sunspace to the earth mass in the crawlspace plenum.

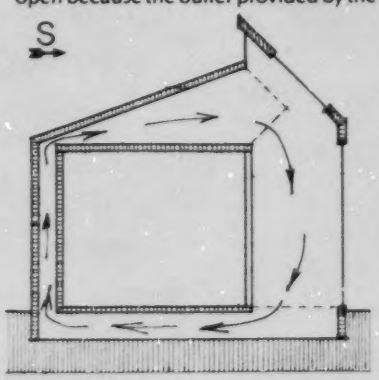


Figure 3. Winter nighttime air flow.

A PERFORMANCE STUDY OF A THERMAL ENVELOPE HOUSE

A performance study of a thermal envelope house located in North Georgia was sponsored by the Southern Solar Energy Center in 1980 (1). The two-story home was monitored in late February and March during the first phase of the study. This included a period when temperatures dropped below 10°F at night and remained below 45°F during most of the day. The second phase of the study concerned monitoring the cooling performance of the house during a July test period.

The instrumentation for Phase One of the study included copper constantin thermocouples (26 gauge premium grade NBS reference) routed to 44 positions within the house, sunspace, attic, north wall cavity, crawlspace, and exterior to determine energy distribution in the thermal envelope and living space. Hot wire anemometers were located in the north wall cavity and in the crawlspace to measure air velocity in these areas. Output from the thermocouples and anemometers were routed to a data logger, which was programmed to sample all channels twice an hour.

An analysis of the data recorded on March 3 gives a good representation of the performance of the thermal envelope house on a clear, cold day when the outside temperature dropped to 10°F at 7:30 a.m. and reached a maximum of 48°F at 6:00 p.m. The anemometer readings on this day were very low with air flow never exceeding .5 foot per second. It should be noted that this rate occurred in the north wall cavity when temperatures in

the sunspace were highest. The flow rate declined thereafter until air flow was virtually stagnant during the night.

At 8:00 a.m. on March 3, temperatures at the peak of the sunspace had fallen to a low of around 44°F by 8:00 a.m. This was still 34 degrees above the outside ambient temperature, which was 10°F. Since the sunspace has very little thermal storage mass, it responded rapidly to incident solar radiation, reaching peak temperatures at about 3:00 p.m. At this time the temperature at the top of the sunspace reached 94°F, which was about 12 degrees higher than the temperature recorded at the bottom of the sunspace.

Temperatures in the attic closely followed temperatures in the sunspace with a lag of about two hours, probably because of low air flow in the envelope loop. Temperatures in the north wall cavity also showed a response to solar input from the sunspace. Recorded data showed the temperature decreasing from 76°F to 68°F as the air moved down the north wall at 4:30 p.m. However, during the early morning the temperature difference between the top and bottom of the north wall cavity was only two degrees, ranging from around 48°F at 1:00 a.m. to about 45°F at 8:00 a.m.

Because there has been much speculation on how the earth mass in the crawlspace plenum of an envelope loop performs, temperatures were measured in several areas of the crawlspace as well as at various depths below grade. This was done to determine whether excess heat was stored in the earth mass and later released at night. Figure 4 shows that temperature changes did occur in the crawlspace although the temperature never rose above 63°F. Because of low air velocity, the warmer temperatures occurred at the top of the crawlspace, near the first level floor. Consequently, little if any energy was transferred to the earth. The lack of energy transfer to the earth actually made little difference since the temperature of the air in the crawlspace was too low to be considered useful. Even at its peak, it was never higher than the temperature desired in the living space.

Analysis of the temperatures around the loop showed that, although large quantities of solar energy were collected

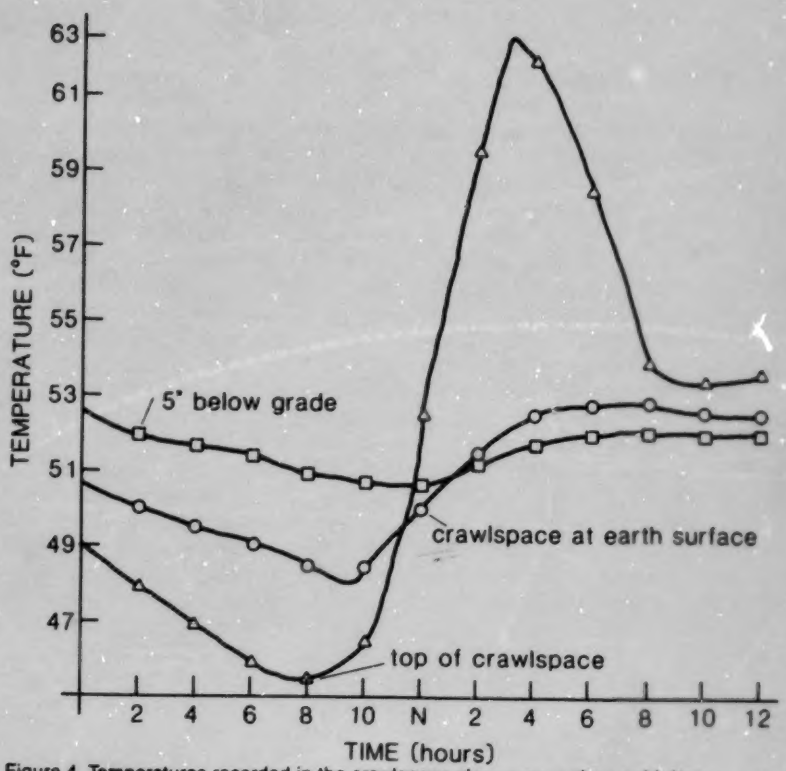


Figure 4. Temperatures recorded in the crawlspace plenum on a clear, cold day.

by the sunspace, very little energy reached the north wall and none of the energy was stored in the ground. Thus, it appears that a significant amount of energy is being lost in the attic. In the case of this particular house, these losses are probably beneficial because they prevent serious overheating of the interior living space.

Temperatures within the living space were found to be in the moderate range, fluctuating in a manner similar to a well-insulated, low mass house. Temperatures in the living room dropped from around 76°F at midnight to a low of 63°F by 8:30 a.m. The benefit of the sunspace can be seen in a comparison of temperatures at 8:30 a.m. between the outside (10°F), the sunspace (43°F) and the living room (63°F). Had the sunspace not been present, the difference between the temperature of the living space and the adjoining air temperature would have been 53 degrees rather than 20 degrees. The heat transfer rate would have been much higher with the greater temperature differential causing the living area to lose a lot more of its heat to the outdoors.

The major benefit of the north wall cavity also seems to be that of a thermal buffer. It was found that energy was never transferred from the envelope loop through the north wall to the living space because temperatures within the wall cavity remained below interior temperatures. However, solar energy reaching the north cavity during the day did function to reduce heat loss from the interior through the north wall. For example, in the early morning on March 3, the temperature difference between the interior north wall (63°F) and the north wall cavity (44°F) was only 19 degrees because of the presence of the outer insulated wall. Had the exterior insulated envelope not been present, the temperature difference would have been 53 degrees, resulting in significantly higher heat loss to the outside.

Overall, the thermal envelope home monitored in this study peformed quite well in winter. It was able to maintain comfortable interior temperatures with

little use of the auxiliary heating system. On a sunny day, air was warmed in the sunspace and rose to induce air circulation in the loop. However, because of low air flow rates and high energy losses through the attic and north wall, the air reaching the crawlspace had little energy available for storage. Also, air circulation did not reverse at night. Although the thermal envelope home did not function as was originally postulated by early designers, it did perform like a well-insulated home. Periodic use of a wood stove and internal gains from people, lights, and appliances were sufficient to keep the home comfortable throughout the winter months.

In Phase Two of the study, measurements were made to determine how well the same thermal envelope home performed during the cooling season. The home under study employed a thermal chimney and earth cooling tubes. Two 100-foot long earth cooling tubes supplied earth-tempered air to the crawlspace plenum. This cooled air was then circulated around the envelope and exhausted through the thermal chimney. An attic fan was installed to help circulate the air. In theory, the thermal chimney, a relatively high vertical structure, would heat the air inside it, causing the air to rise and exit out the top of the chimney. This would then draw the cooler air from the earth cooling tubes into the thermal envelope.

The instrumentation for the cooling performance evaluation was similar to that used for Phase One of the study except that additional thermocouples were used to measure temperatures along the earth cooling tubes. Additional hot wire anemometers were also positioned to measure air flow through the earth tubes.

Analysis of the measurements during the July test period showed that the earth cooling tubes provided sensible cooling to the house. Temperatures at the tube exit were between 72-76°F while outside ambient temperatures were in the 80's, reaching a peak of 93°F. During this time temperatures in the interior of the home were within the moderate range with a peak temperature of 80°F.

It was found that the thermal chimney did not perform well in moving air within the envelope. The highest velocity recorded within the envelope was quite low, at less than one foot per second even when the attic fan was operating. The thermal chimney also did not help induce good air flow through the earth cooling tubes. At times the difference in air density between the thermal chimney and earth tubes would cause the air to flow in a reverse direction – in through the chimney and out the earth cooling tubes. Using the attic fan helped to increase air flow somewhat and move it in the right direction through the tubes and around the envelope.

The main problem with the cooling performance of the thermal envelope home studied was high humidity levels. The living space had relatively high humidity levels throughout the year because of low air infiltration and water vapor transmission through the building's exterior walls. These levels were increased in the summer by the introduction of cool moist air from the earth tubes, which were able to reduce air temperatures but were incapable of reducing humidity levels. The humidity in the air from the earth tubes need not affect comfort in the home as long as the earth-cooled air is isolated in the envelope. In practice, however, the interior was frequently opened to the envelope, resulting in high humidity levels within the living space.

COMPARISON OF THERMAL ENVELOPE WITH OTHER HOUSING TYPES

Many analysts attribute the good performance of thermal envelope homes to their high insulation levels. One study compared the interior wall temperatures of a thermal envelope design and a superinsulated structure (2). The well-insulated wall had R-30 insulation and each of the two envelope walls had a value of R-15. The study found that the difference in interior wall temperatures was less than one degree Fahrenheit when the outside temperature was 0°F and the inside temperature was 70°F. Since the performance of thermal envelope and well-insulated houses is so similar, many designers feel there is little justification for the extra expense in constructing a thermal envelope design with its two finished walls.

Another study used computer simulations to compare the performance of a thermal envelope structure with a conventional home and a single wall passive solar home with a large sunspace and fan-forced rockbed storage (3). The thermal envelope house used significantly less auxiliary space heating energy than the conventional home but more than twice the energy of the single wall passive solar home. Even when the energy required to run the fan was added to purchased auxiliary energy, the sunspace home with rockbed storage still consumed about 22% less energy than the thermal envelope design.

Of course these studies only consider the energy performance of the thermal envelope and do not consider the aesthetic, social, and psychological benefits of the double envelope. Most homeowners are very pleased with their thermal envelope homes. These proponents, people who have lived in thermal envelope homes, certainly make a good case for the thermal envelope design as an attractive energy-conserving alternative to conventional housing.

REFERENCES

1. Akridge, James M. and Benton, Charles C. *Performance Study of a Thermal Envelope House: Phase I* and *Performance Study of a Thermal Envelope House: Phase II*. Atlanta, Georgia: Southern Solar Energy Center, 1981.

2. Reno, Vic. "Shakedown for the Envelope House: A Physicai Exam," *Solar Age*, November 1980, pp. 14-21.

3. Koehler, Joe and Lewis, Dan. "Trial by Computer," *Solar Age*, November 1980, pp. 22-27.

5 Wind

Interim Report on Wind Energy in Arkansas

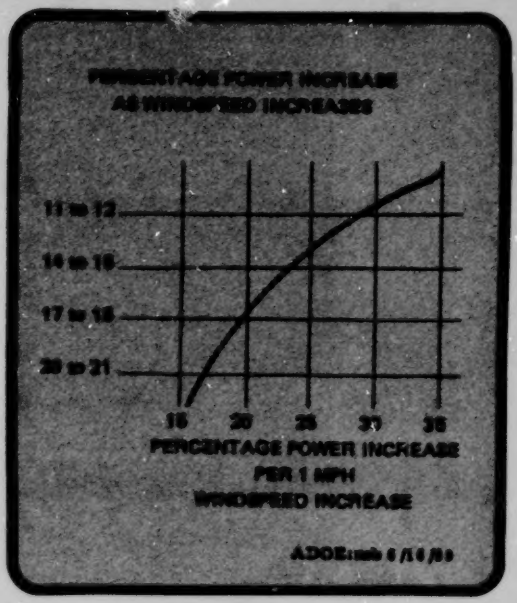
Wind energy has some potential for providing electrical power to Arkansans, but a detailed wind-regime analysis must be conducted before valid economic conclusions can be drawn. Because the amount of power available in wind increases exponentially as the windspeed increases arithmetically, average windspeeds and general data are of little use to the wind prospector. Additionally, windspeed information taken for weather-forcasting and pollution-control purposes is usually not taken at heights that would be representative of a wind generator's position.

OVERVIEW

Doubling the windspeed cubes the amount of power available. A windspeed of 20 mph has 8 times (2^3) as much power as a 10-mph wind and 64 times as much power as a 5-mph wind. Because power cubes as windspeed doubles, a small recording error in windspeed measurement may produce a substantial error in power-production estimates.

A typical wind generator will not 'cut in' or begin producing power in winds of less than 7 to 10 mph. There is no great loss by its inactivity at lower speeds because there is very little power in those lower winds. Most generators produce power up to only 25 to 30 mph, at whch point they feather out of the plane of the wind to prevent generator burnout and other damage caused by rotation above design speed. Some generators continue to produce their rated power production in high-speed winds.

Average windspeeds are not very helpful in determining the amount of power available in a given wind regime. Let's say two sites each have an average windspeed of 8 mph. At site one the wind blows a steady 8 mph. At site two the wind blows 4 mph half the time and 12 mph half the time. Assume your machine cuts in at 10 mph. Site one has produced no power, but site two has produced power half the time even though both sites have the same average windspeed. This example shows us that the only way to determine the amount of power a wind turbine will generate at a given site is to obtain detailed recordings of winds, which include duration of each windspeed as a primary factor. Such information may be obtained with a strip chart recorder or through an analog data receiver, which can then be analyzed by computer.



Although wind prospecting in flat, open areas is fairly indicative of readings from any

site within several miles, this is not the case with mountainous or hilly terrain, urban areas or areas close to large bodies of water. These areas are known as complex terrain. Much of Arkansas is complex terrain with regard to wind prospecting. Recordings in complex terrain are very site-specific and cannot be assumed to be indicative of the wind regime at other locations in the area. Shading of a wind generator can be caused by any obstruction within 500 feet that is within 10 feet of the height of the generator.

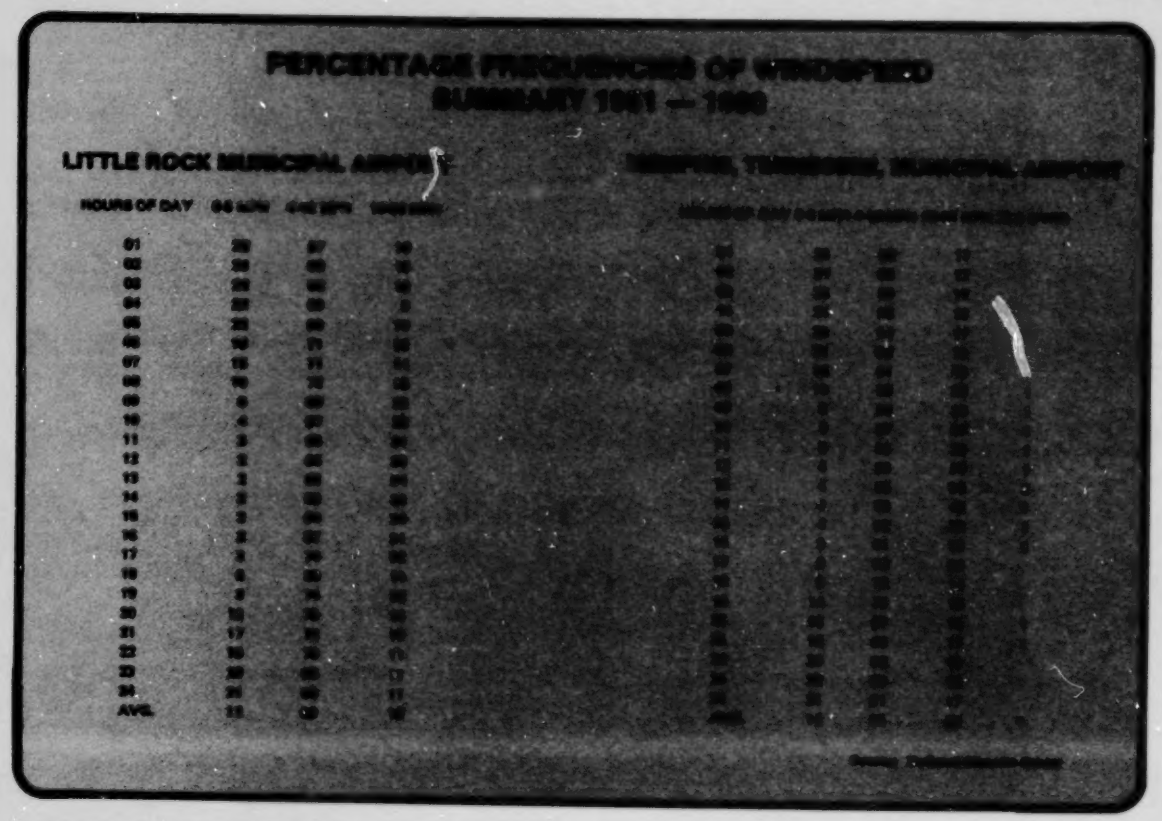
ARKANSAS' WIND PATTERNS

There is reason for cautious optimism about the wind energy potential in Arkansas, based on what sketchy data is available. A computer-simulated analysis of national wind patterns shows that the mountainous areas of Arkansas have an average of 400 to 500 watts per square meter per hour mean annual wind energy. Some shoreline areas will probably also have this much power available. A machine with a 14-foot-diameter rotor and a coefficient of power (C_p) of three-tenths (typical of several machines on the market) will produce 1250 KWh per month in a regime of 400 watts per square meter or 1566 KWh per month in a regime of 500 watts per square meter.

Summarized statistics from 1951 through 1960 indicate that at 20 meters, the average windspeed was 8.7 mph at Adams Field, 6.7 mph at the Fort Smith Municipal Airport, and 9.4 mph at the Memphis Municipal Airport.

In Little Rock, the wind blew 8 mph or harder 58 percent of the time. A typical wind turbine would have been generating some electricity during that 58 percent of the time. The exact amount of power extractable from those winds would vary from machine to machine, depending on the machine's tip speed ratio (ratio of blade tip speed to windspeed), blade length, generator efficiency and windspeed. During the 18.5 percent of the time the windspeed exceeded 12 mph, most machines would have been generating significant power.

It is encouraging to note that the strongest winds coincide roughly with peak demand. If long-term data can be compiled that verifies



WIND DISTRIBUTION

LITTLE ROCK

	CALM	1-3	4-6	7-10	11-16	17-21	>21	>11 MPH
	% OF TIME	% OF TIME	% OF TIME	% OF TIME	% OF TIME	% OF TIME	% OF TIME	% OF TIME
DECEMBER JANUARY FEBRUARY	4.2	4.7	31.1	46.5	19.6	10.6	0.3	30.5
MARCH APRIL MAY	5.9	5.1	33.5	36.2	16.5	1.7	0.2	30.4
JUNE JULY AUGUST	7.3	8.3	46.4	32.6	6.6	2.6	0.2	8.8
SEPTEMBER OCTOBER NOVEMBER	7.3	8.2	46.5	33.7	10.7	0.4	1.9	11.1
ANNUAL	6.2	6.6	37.4	36.6	13.7	10.6	1.3	26.5

MEMPHIS

	CALM	1-3	4-6	7-10	11-16	17-21	>21	>11 MPH
	% OF TIME	% OF TIME	% OF TIME	% OF TIME	% OF TIME	% OF TIME	% OF TIME	% OF TIME
JANUARY	5.0	4.0	34.0	33.0	20.0	4.0	0.0	23.0
FEBRUARY	3.0	6.0	16.0	31.0	33.0	6.0	6.7	26.0
MARCH	3.0	4.0	16.0	31.0	44.0	6.0	0.3	50.0
APRIL	3.0	6.0	16.0	34.0	35.0	7.0	0.0	20.0
MAY	6.0	10.0	20.0	30.0	33.0	1.0	---	24.0
JUNE	4.0	10.0	20.0	30.0	13.0	0.0	---	13.0
JULY	7.0	10.0	27.0	25.0	0.0	---	---	0.0
AUGUST	10.0	16.0	40.0	27.0	3.0	---	---	3.0
SEPTEMBER	7.0	6.0	25.0	35.0	10.0	0.3	---	10.0
OCTOBER	6.0	6.0	30.0	30.0	16.0	0.0	---	17.0
NOVEMBER	5.0	6.0	20.0	30.0	30.0	3.0	---	33.0
DECEMBER	1.0	4.0	21.0	30.0	31.0	3.0	0.0	34.0
ANNUAL	5.0	6.0	27.0	22.0	22.0	3.0	0.2	24.0

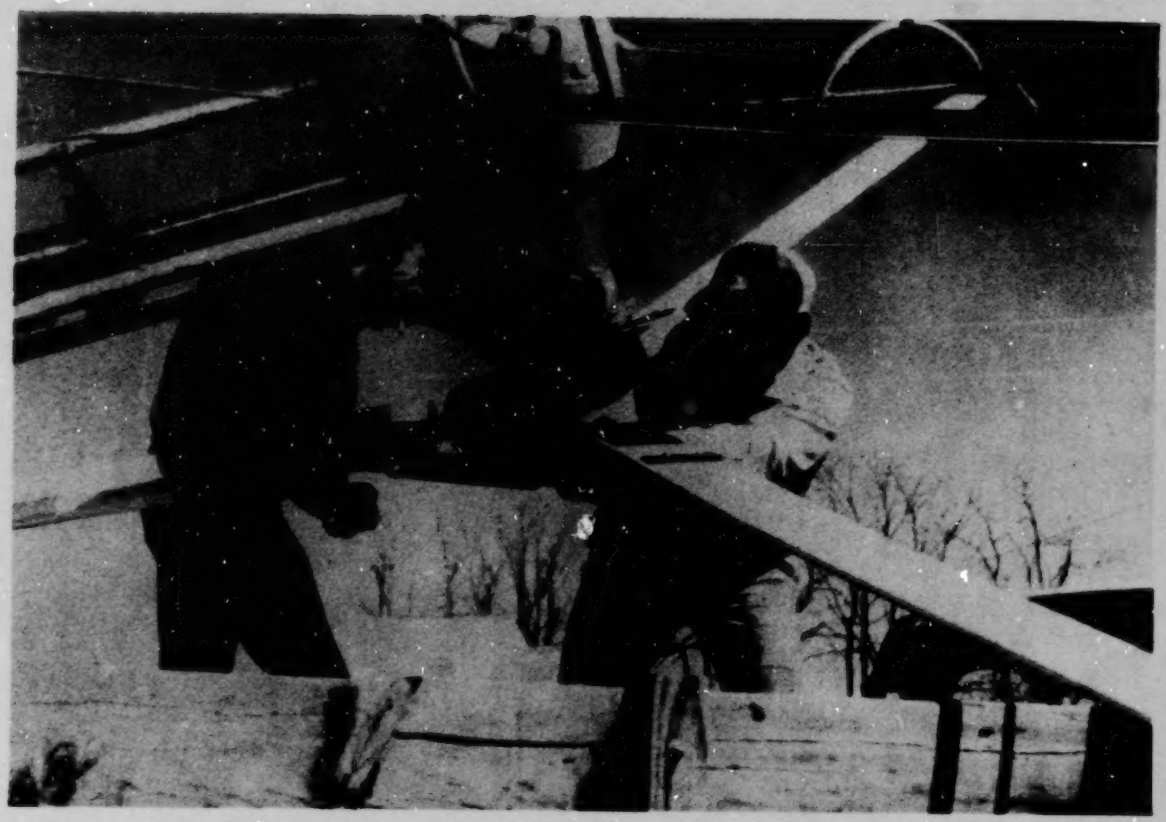
FORT SMITH

	CALM	1-3	4-6	7-10	11-16	17-21	>21	>11 MPH
	% OF TIME	% OF TIME	% OF TIME	% OF TIME	% OF TIME	% OF TIME	% OF TIME	% OF TIME
JANUARY	5.4	5.0	32.0	34.0	14.0	1.0	----	15.0
FEBRUARY	7.0	7.0	38.0	36.0	17.0	1.0	2.0	18.0
MARCH	4.0	6.0	36.0	35.0	20.0	2.0	0.4	22.0
APRIL	5.4	7.0	33.0	36.0	20.0	2.7	0.3	23.0
MAY	6.0	9.0	34.0	33.0	9.0	1.0	0.1	10.0
JUNE	5.1	9.0	40.0	31.0	8.0	0.8	----	10.0
JULY	5.3	11.0	46.0	30.0	6.0	0.3	----	6.0
AUGUST	5.0	11.0	46.0	30.0	6.0	0.1	----	6.0
SEPTEMBER	6.0	10.0	42.0	30.0	7.0	0.4	----	7.0
OCTOBER	10.0	10.0	41.0	29.0	8.0	0.3	0.1	8.0
NOVEMBER	6.0	6.0	34.0	33.0	13.0	1.0	----	14.0
DECEMBER	7.0	6.0	33.0	34.0	16.0	1.0	0.2	16.0
ANNUAL	7.0	6.0	36.0	32.0	13.0	1.1	0.1	14.0

Source: National Climatic Center

the dependability of wind generation at peak times of day, wind machines might at some point qualify for a capacity displacement credit both on the small-end-uses and utility scales. Small power producers who cogenerate back into the utility grid are required to be metered by time-of-day metering. This means simply that the user pays more for power consumed during the peak and near-peak hours and conversely is paid more for any power contributed during that time. Rates during non-peak hours are lower for the buyer and the seller.

A much closer look is necessary before we can know the actual potential of wind energy in Arkansas. The wind energy industry is developing quickly, and long-life, high-reliability equipment is beginning to be marketed. There are already a handful of machines on the market that look like they will be serviceable for 20 years or more. If a comprehensive wind energy assessment for the state is initiated soon, we will have the information that Arkansans will need to make appropriate consumer decisions as the industry matures.

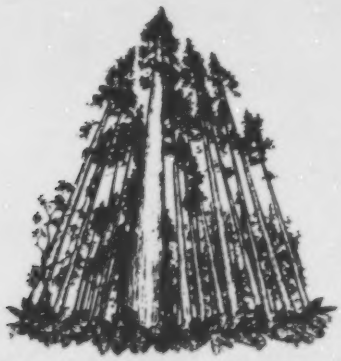


The Ozarks have become home to a number of windpower projects, and new wind machines such as this one are going up regularly. To learn about the successes and failures of Arkansas wind enthusiasts, read Achieving Self-reliance: Backyard Energy Lessons, *the companion volume to* Free! New and Improved Energy for Arkansas.

6 Biomass

WOOD HEATING

Arkansas is a good place to live if you wish to heat your home with wood. Half the state is in timberland, and much of that may be used by the public as a source of firewood.



The Arkansas Forestry Commission provides firewood permits without charge to those who wish to cut their firewood in state forests. State foresters will locate proper trees for the cutting, as well. The contact is:

Mr. Harmon Ross
Box 955
Camden, AR 71701
(501) 835-5882

A $10 permit may be obtained in the national forests, where foresters will designate an area in which to cut wood, and a limit of approximately 100 cubic feet a season is in force. Call the office of the district ranger nearest you to arrange for your permit.

In the Ozark National Forest, those offices are:

Hector — 284-3150
Ozark — 667-2191
Paris — 963-3076
Jasper — 446-5122
Clarksville — 754-2864
Marianna — 295-5276
Mountain View — 269-3229

In the Ouachita National Forest, those offices are:

Glenwood — 356-3523
Booneville — 675-3233
Hot Springs — 321-5296
Perryville — 889-5176
Mena — 394-2382
Waldron — 637-4174
Oden — 326-4322
Danville — 495-2844
Mount Ida — 867-2101

The Weyerhaeuser Company allows firewood cutting in its forests for free. Permits are obtained at a curbside box outside the Hot Springs office at 810 Whittington Avenue or at a curbside box outside the main office at Mountain Pine. Contact the Forestry Department of the company in Mountain Pine at 767-7233 if you have any questions.

International Paper Company permits firewood cutting, and charges a nominal fee for the permit. The company directs the cutting. Timber offices of International Paper should be contacted to arrange for the permits, and these are located at Sheridan, Arkadelphia, Pine Bluff and Camden.

By state law, 100 percent of the cost of wood-energy equipment may be deducted when you prepare your state income-tax form. Tax officials define wood energy items to include wood stoves and furnaces, along with components of wood stoves or furnaces such as flue pipes, dampers and chimneys specifically necessary for the installation of wood-burning equipment. Excluded are traditional fireplaces.

All installations must meet specifications in the Arkansas State Fire Code in order to qualify for the tax deduction.

Also deductible is the cost of converting a traditional fireplace to an enclosed firebox that uses heat exchangers and thermostatically-controlled dampers and blowers, and outside air combustion capability if possible.

Another deductible item is a heat-recovery unit such as a flue-heat extractor, which recovers flue-gas heat and uses it for space heating or water heating.

To perform at its best, wood should be cut, split and dried at least six months before it is burned, so make plans to heat with wood well in advance of the winter season.

Burning well-seasoned wood is a safety precaution, as well, since green wood tends to hasten the corrosion of stoves and chimney systems.

If you purchase your wood, be careful to get what you pay for. The standard measurement for the sale of wood is a cord — 128 cubic feet. This represents wood stacked in a pile measuring eight feet long, four feet wide, and four feet high.

A lesser measure is a face cord — a pile of wood eight feet long, four feet high and as wide as the lengths of cut wood, usually one or two feet.

A standard pickup will hold only a third to a half of a full cord. For a stove, order stovewood — 16 inches long. This will burn the best, and be the easiest to handle.

Like other products, it is illegal to deliver less firewood than is advertised and paid for. The Consumer Protection Division of the Attorney General's office will protect you against unscrupulous dealers. Call 371-2341 in Little Rock or toll-free 1-800-482-8982.

Sawmill slabs and edgings may be available for firewood for a small charge, or even free, although they tend to be in lengths up to 16 feet, and may have to be cut into shorter pieces.

Construction sites at landfills may also be a source of firewood to those equipped and willing to haul wood, and cut it.

Be very careful of any wood scraps you take for your woodstove, and make sure you are not burning greenish, pressure-treated wood designed for outdoor use in decks and similar projects. That wood is treated with chromate-copper-arsenate (CCA) and those chemicals can be taken into the system if burned indoors. These poisonous chemicals may cause pneumonia, conjunctivitis, skin rashes, nosebleeds, blackouts and seizures, gastrointestinal disturbances, and severe hair loss, among other ills.

Scrap wood is a clever way to heat for free; just be sure you don't take home some poison at the same time!

FOR CUTTING WOOD, HAVE:

Buck or Chainsaw

Axe

Splitting Maul or Sledge Hammer

Wedges

Saw Buck or Sawhorse

Cord Wood Saw (optional)

Hydraulic Splitter (optional)

Utility companies clear branches away from overhead lines, and these may be available for firewood by checking with utility officials in your town.

What type of wood is best for heating? The heaviest, most dense wood gives the best heat value for the money.

Shagbark hickory gives the most heat per pound, and next in value is white-oak wood, followed by American beech, red oak, sugar maple and yellow birch.

The least heating value comes from eastern white pine and aspen wood.

Small pine sticks, pine cones, paper and cardboard all are good kindling with which to start a wood fire.

NEVER USE GASOLINE or a flammable liquid to start a fire; an explosion could level the entire home.

Another fuel source is old newspapers or magazines, rolled tightly, soaked in water, then dried near a heat source. The moisture helps fight winter dryness in a house, and once dry, paper logs burn almost like wood.

Check the damper in the chimney when you start a fire and be sure that it is opened, to draw off the smoke. When the fire is put out, be sure the damper is closed, or you can waste a lot of heat.

An open wood fire is not efficient, and it can even cool down a house; this is because large amounts of cold air are drawn into a house to feed oxygen to the flames.

FOR BURNING WOOD, HAVE:

Stove or Fireplace

Chimney
(masonry or prefabricated metal)

Stovepipe and Accessories
(elbows, fittings, dampers, and asbestos sheeting, and brick, stone or metal floor-covering)

Safety Inspection

Fire-tending Tools
(ash shovel, metal ash bucket, poker or tongs)

Fire Extinguisher

Smoke Detector

Wood Box

A properly-sized Chimney Brush

In addition, much of the heat from the fireplace goes up the flue and never heats the room.

By burning wood and coals slowly, you can produce more heat. One way to slow the burning process is to control the amount of air allowed into the fire.

Modern fireplaces often are equipped with a control vent at the front that draws in cold, outside air, to fuel the flames. In this way expensive, heated air in the home is not sucked up the chimney, and you can extract more heat from the wood. This is especially useful in airtight houses; it may not be so helpful in other homes, and may cause greater wood consumption.

FIRE HAZARDS

- Logs drying on the stove
- Stove too close to wall
- Inadequate floor protector under stove
- Rugs, papers or other flammable items too close to stove
- No air gap behind the wall protector behind the stove
- No wall protection around the stovepipe at the point it passes through the wall
- Stovepipe too close to ceiling
- Unsecured joints in the stovepipe that can fall apart
- Creosote oozing out of the stovepipe at joints, which may ignite
- Chimney too short to carry away sparks from the roof
- Flames escaping through cracked chimney
- Insufficient insulation between chimney and roof

Investigate thermostats for stoves when you go shopping. These controls for wood and coal stoves operate the same as a thermostat on other heating systems. A bimetallic coil attached to the air inlet dampers winds up or unwinds in response to the temperature. This regulates the amount of air admitted to the fire, and that controls the heat given off. The knob on the

GUIDELINES FOR STOVES

1. For continuous heating, ease of operation is important; this will be supplied by a stove that holds a relatively-large amount of wood, and burns the wood steadily.
2. Airtightness is important to obtaining a steady output of heat at low rates of wood use; inspect the stove you like for cracks.
3. In mobile homes, a small circulating stove may work best. There are special stoves for mobile homes and use of another kind can be disastrous. Use of another kind also may void insurance policies on the mobile home.
4. Both cast iron and steel plate are suitable materials for stoves. Steel can warp; a minimum of 24-gauge steel should be used in the flue. Cast iron can crack, but does so rarely. Both can rust. The thicker the material, the longer the life expectancy.
5. Inspect all parts of the stove and chimney regularly and clean the chimney at least yearly.
6. Heat radiating out from the stove, stovepipe or chimney should be handled with proper clearances between the stove and surrounding, flammable objects. A distance of 36 inches should separate a stove from any combustible surface; the stove may be placed closer to a protected surface. Protection may be provided by sheet metal or asbestos millboard, with at least one inch of air space behind it.
7. The single-wall pipe should be kept 18 inches from any flammable surface.
8. On the roof, see that the chimney extends two feet above anything else within a ten-foot radius.
9. Mount the stove over a protected floor that has a covering of 24-gauge sheet metal, quarter-inch asbestos millboard covered with 24-gauge sheet metal, mortared bricks, concrete, or similar material.
10. Install a floor covering under the stove that extends at least 18 inches beyond the stove at the point where the wood is loaded, and that extends 12 inches beyond the stove on the other sides.
11. For a six-inch stovepipe, a hole at least 18 inches in diameter should be cut through the wall, and a coliar, or thimble, should be installed to hold the pipe. The thimble should be supported in the middle by sheet steel or asbestos millboard on either side of the hole.
12. Buy an "all-fuel" chimney if a factory-built metal chimney is used; these are designed to withstand more severe conditions than others.
13. Insist upon safe installation of the stove you select — most fires related to wood heating may be traced back tc unsafe installations.
14. Do not dry out wet or green wood on top of a stove; this may cause a fire.
15. Always leave about an inch of ash in the bottom of the stove, unless the bottom has firebrick or an ash drawer.
16. Check to see that the stove of your choice has an Underwriters Laboratories (UL) label and has been tested for safety. Listed equipment is likely to last a reasonable time, ar d is not so likely to fall apart when used.

outside of the stove rotates the coil as a whole; setting the knob is like selecting a temperature on an ordinary thermostat.

All wood fires generate creosote — this is a black tarry liquid that results from the condensation of wood gases not burned in the combustion process. There is no way to prevent the formation of creosote, but it can be minimized by avoiding smoldering fires, burning seasoned hardwoods and using interior chimneys. When allowed to accumulate in large amounts, it could fuel a chimney fire.

The simplest cleaning method to use is a wire chimney brush and extension handles. One person can brush out the chimney in stages — by pushing the brush in the chimney, scrubbing the walls, then adding a brush extension and continuing to push the brush up the flue.

The brush also could be pulled up and down the chimney by two ropes, with one person pulling up from the roof, and the other pulling down from below.

One person could pull the brush up and down the chimney using a rope and a weight.

FOR FURTHER INFORMATION

Wood Heat Safety by Jay W. Shelton, published by Storey Communications, RD 11, Box 105, Schoolhouse Road, Powmal, VT 05261, $8.95.

Solid Fuels Encyclopedia by Jay W. Shelton, published by Storey Communications, $12.95.

Woodburners Encyclopedia by Jay W. Shelton, published by Vermont Crossroads Press, Box 30, Waitsfield, VT 05667, $7.95.

Country Journal articles: "Woodburning, "Which Wood?," "Woodburning Furnaces," and "In Search of the Safe Chimney, " available for $1 each plus $1 postage, or $5 for the package. Write **Country Journal,** 205 Main Street, Brattleboro, VT 05301, Attention: Paula Bunyan.

"Wood Stove and Fireplace Inserts," **New Shelter,** September, 1981. Send $1.50 to 33 East Minor Street, Emmaus, PA 18049.

Country Journal Woodburner's Cookbook, by Janet Chadwick. Send $9.95 to **Country Journal,** 205 Main Street, Brattleboro, VT 05301, Attention: Sara Fisher.

"Childproofing Your Wood Stove," **New Roots,** Winter, 1982. Send $1.75 to Box 548, Greenfield, MA 01302.

Fire Safety of Woodburning Appliances, 1. Code No. PB 81-145823. Send $7 to the National Technical Information Service, Springfield, VA 22161.

"Saving Energy Dollars," **Consumer Reports,** October, 1981. Send $1.50 to Box 1949, Marion, OH 43305.

"Fireplace Inserts," **Canadian Consumer,** June, 1981. Write Circulation Department, 200 First Avenue, Ottawa, Ontario, Canada K1S5J3.

Advanced Woodburning Technology Evaluation: Summary Report, by Jay B. Shelton, published by Shelton Energy Research, Inc., Box 5235, Santa Fe, NM 87502.

Getting Warm without Getting Burned: Common Sense about Wood Stoves. available from NCAT Publications, Box 3838, Butte, MT 59702, $1.95.

Annotated Bibliography of Wood Energy Periodicals. available from Resource Policy Center, Box 8000, Thayer School, Dartmouth College, Hanover, NH 03755, $3.

Wood Burning Furnaces: Technology and Evaluation. 1978-October, 1983. available from the National Technical Information Service, $35.

Wood Heating Alliance, Carter Keithley, Executive Director, 1101 Connecticut Avenue NW, Suite 700, Washington, D. C. 20036. Phone: 202-857-1181.

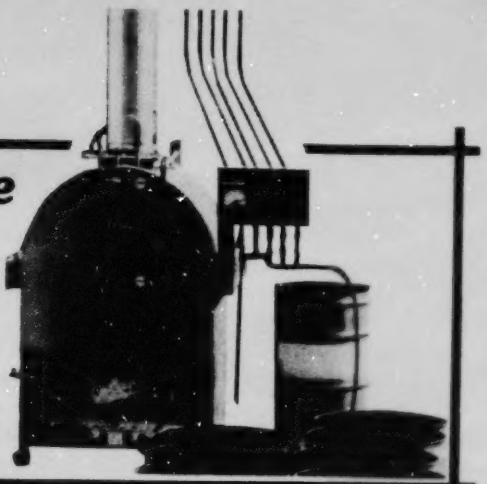
National Chimney Sweep Guild, Box 1314, Nashua, NH 03061. Phone: 603-880-7831.

"Catalytic Converters for Wood Stoves," Robert Harlan. **Popular Science,** January, 1982. Available from Box 2871, Boulder, CO 80302.

Furnaces Utilizing Loose Sawdust. Code No. DE83015857. Available from the National Technical Information Service, for $7.

Arkansas Energy Future

Alcohol



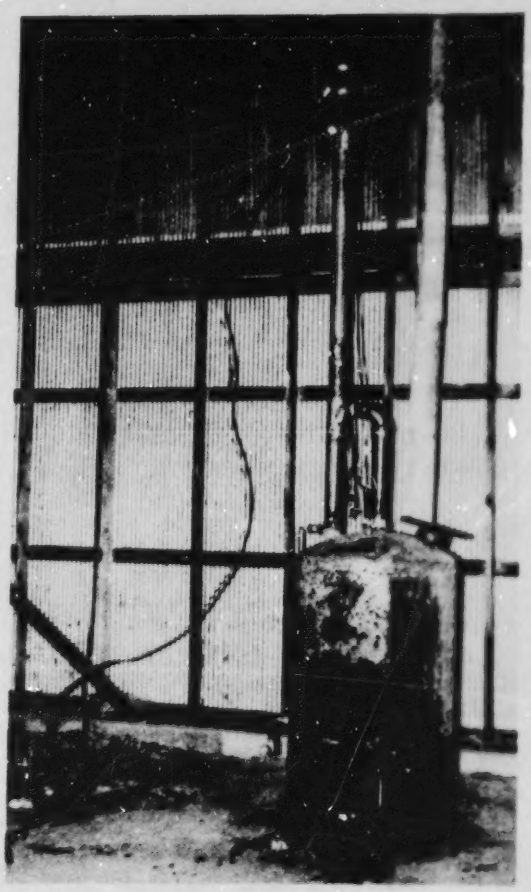
INTRODUCTION

Events of the past decade have clearly indicated that Arkansas' growing demand for motor vehicle fuel cannot continue to be met by traditional sources at traditional prices. As the more economically attractive domestic oil is being depleted, the nation has turned increasingly to imports, which have proven both costly and undependable. A transition is needed from the current petroleum-based motor vehicle fuel to a fuel that can be processed domestically, from domestic renewable resources.

Alcohol is one such fuel that can be manufactured in Arkansas from Arkansas-grown feedstocks. The production and use of alcohol as a motor fuel holds great potential for both the fuel consumer and the fuel producer. Additional markets for domestically-produced agricultural products can be obtained through the construction and operation of alcohol fuel plants. Therefore, by producing and using alcohol as a fuel, the state and the nation will benefit economically by putting Arkansans to work constructing and operating alcohol plants, adding markets for Arkansas-grown feedstock, and reducing the national trade deficit by curbing the importation of foreign oil.

INCENTIVES FOR THE PRODUCTION OF ALCOHOL IN ARKANSAS

Alcohol fuels can contribute to state energy supplies by using renewable resources to extend supplies of high-quality liquid fuel. Unleaded gasoline and alcohol blends can supplement scarce petro-fuel supplies, both as an extender and an octane improver. It has been predicted by the United States Department of Energy that, in the near term (1979-



This is one example of the many homemade stills popping up throughout Arkansas.

1985), alcohol's contribution to the nation's motor vehicle fuel supplies will come, primarily, in the form of alcohol-gasoline blends, commonly called gasohol. However, alcohol also offers great potential, especially in farm use, as an unmixed motor fuel.

In an effort to promote the use of alcohol fuels manufactured from alternative sources of raw material, the federal government has removed the four-cent-per-gallon federal excise tax from the product gasohol. Gasohol, as defined by the federal government, is a mixture of at least ten percent alcohol made from alternative feedstocks (anything except oil or natural gas or a product derived therefrom), and up to ninety percent gasoline.

Small-scale ethanol production can take advantage of the types of crop storage and handling equipment already in use on the farm.

Likewise, Arkansas has removed the entire 9.5-cent-per-gallon state motor vehicle fuel tax from gasohol. As defined by state legislation, gasohol is a blend of at least ten percent alcohol, manufactured in Arkansas from renewable resources, and up to ninety percent gasoline. By combining the federal and state market tax incentives, a total market tax incentive of 10.5 cents per gallon of gasohol can be obtained. Sales tax is due on alcohol at a rate of three cents per gallon. When we subtract three cents for sales tax, we have a 6.5 cent market tax incentive. Add back the federal excise tax exemption of four cents per gallon, and the total incentive is 10.5 cents per gallon. By multiplying this 10.5 cents market tax incentive by a factor of ten, up to $1.05 can be obtained in the form of a market tax incentive, for each gallon of alcohol manufactured, blended and sold in Arkansas in the form of gasohol. Multiply by ten because that is the portion of the fuel gasohol that may be alcohol, according to state and federal law.

The Federal Government offers a ten percent **Investment Tax Credit** for all new equipment and facilities purchased for industrial production. This tax credit is available for commercial fuel alcohol plants.

In addition, the federal government also offers a ten percent tax credit for new equipment and facilities used for the production of alternate fuels. This credit is known as the **Alternate Energy Property Tax Credit,** and when combined with the **Investment Tax Credit,** yields a twenty percent total tax credit for equipment and facilities capitalized for the production of fuel alcohol.

PROCESS FOR MAKING ETHANOL ALCOHOL FOR FUEL

When an individual decides to investigate making alcohol fuel, one of the first things that must be done is to determine what raw material will be used to make alcohol. It is possible to make alcohol from almost any organic material. Three types of organic material generally used to make alcohol are sugar, starch, and cellulose. All of these fall into the category of carbohydrates. Due to economic factors, abundant supply and relatively simple processing procedures, starch has been in the past and is today the principal carbohydrate used as a feedstock for making fuel alcohol. For this reason, we will examine the process for converting starch to alcohol.

There are many so-called starch crops that can be used to make alcohol. Examples of starch crops are corn, potatoes, barley, grain sorghum, wheat, rice, and oats. Examples of crops that can be grown in Arkansas and their yield of 197 proof alcohol are given in Table 1.

TABLE 1

Alcohol Yields From Various Crops

Material	Gallons/ Ton	Gallons/ Bushel
Corn	96.4	2.7
Wheat	86.6	2.6
Barley	68.3	2.05
Potatoes	37	1.11
Oats	63	1.05
Sugar Beets	22.1	.72
Rice	79.5	2.3
Grain Sorghum	79.5	2.6
Sorghum Cane	70.4	-0-

MASH PREPARATION

Preprocessing or grinding the chosen raw material is necessary for efficient processing. This makes the starch in the raw material more accessible to the water, heat and enzyme actions that must take place while processing it into alcohol. Grinding the material into flour is not necessary; however, obtaining a material that has a consistency that approaches that of cornmeal is desirable. A hammermill similar to the ones found on many farms is sufficient to grind the raw material to the extent desired.

The alcohol processing equipment should be kept as clean as possible, in order to aid in the prevention of unwanted bacteria cultures in the mash mixture. These bacteria cultures can be harmful to the hydrolysis and fermentation processes. By raising the temperature of the mash to 250° F for 20 minutes, under 15 pounds of pressure, the mash mixture will be sterilized. This will gelatinize the starch molecules and allow enzymes or acid greater access to the bonds holding the molecules together. Further, the proteins will become insoluble and will be easier to separate from the mash, and will provide better nutrition when fed to animals.

For each bushel of corn used, between 15 and 20 gallons of water should be added. This is less than the total amount needed for fermentation (27 to 28 gallons), but it will require less energy for the cooking process. Then, additional water can be added to the hot mixture to cool it to the proper temperature for fermentation, when that step is begun.

Merely boiling the mash will not sterilize it and will require more energy than pressure cooking. A simple rule to follow is to make the starchy material soft. This can be accomplished by boiling the mash for 30 minutes or pressure cooking the mash at 250° F and 15 pounds of pressure for 20 minutes, or 360° F and 160 pounds of pressure for 30 seconds, or any range of temperatures, pressures and times between these two. The rule to remember is the hotter, the faster. The cooking process will break the starch granule down and expose the bonds holding it together.

HYDROLYSIS-SACCHARIFICATION

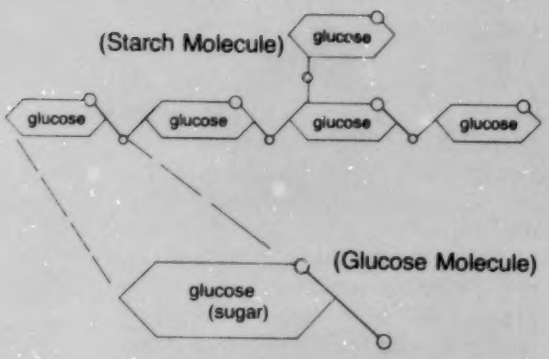
Before cooking, the acid concentration in the mash should be adjusted to obtain a pH of between 6 and 6.5. If the mixture is base, the acid concentration can be adjusted by adding sulphuric or hydrochloric acid in dilute form. The pH level in the mixture can be determined by the use of pH test paper. This is a filter paper material impregnated with certain dyes that change color as the acid concentration changes. Be careful to dilute the acid before putting it into the mash mixture and only use a little at a time.

Approximately 0.3 ounces of alpha amylace enzyme can be added for each 100 pounds of corn in the mash mixture, if you plan to merely boil the mash and not pressure-cook it.

If the more energy efficient pressure-cooking method is used, no enzymes need to be added until the mixture has cooled to 190° F. Then, add 1.5 ounces of alpha amylace per 100 pounds of corn and hold at 190° F for 30 minutes. If the boiling method is used, an additional 1.3 ounces of alpha amylace should be added to the mixture after it has cooled to 190° F.

After maintaining the temperature at 190° F for approximately 30 minutes for either the boiling or pressure cooking method, the mixture should then be cooled to 140° F. This can be done, at least partially, by adding water. At this point, the pH should be adjusted to 4.0, and 4.2 ounces of gluco amylace should be added. The mash mixture should then be held at 140° F for 30 minutes.

FIGURE I
STARCH/GLUCOSE MOLECULE



By this time, most of the starch in the mixture should be converted to free sugar. It is necessary to test for sugar and remaining starch content in the solution. The sugar content can be measured with a Brix hydrometer, simply by filling a test tube with the solution and placing the hydrometer in the tube with the large end down. The contact point between the upper level of the solution and the hydrometer will produce a reading indicating the percentage of sugar in the mixture. Ideally, the mixture should have around 15 percent sugar. If the sugar content is over 20 percent, the yeast will die. Simply adding water to the solution can bring the sugar content down to the recommended 15 percent.

The remaining starch content in the mixture can be determined by placing a few drops of iodine in a beaker of mash. If the mash mixture turns purple, there is still unconverted starch in the mixture. The deeper purple the mixture turns, the more unconverted starch there is present. Allowing a little more retention time for the mash at 140° F will probably take care of most of the unconverted starch.

FERMENTATION

The mash mixture should then be cooled to between 80° F and 90° F. If the sugar content in the solution is 20 percent or greater, cool water can be added to dilute the sugar level to about 15 percent and at the same time, aid in cooling the mixture. When the temperature in the mixture has reached the 80° F to 90° F range, brewer's yeast should be added, in an amount equal to approximately 0.5 to 1 percent of the dry weight of the substrait used to make the mash. (Example: 100 lbs. of corn × 1% = 1 lb. — 100 lbs. of corn × 0.5% = ½lb.) This will start the fermentation process. After having gone through this process a few times, it may be determined that less yeast can be used. The pH level should still be between 4.0 and 4.5, but should be tested before adding the yeast.

A quart or two of the mash mixture can be used to mix with the yeast before introducing it into the rest of the mixture. As the yeast is introduced into the mixture, stir gently. This will mix the yeast into the mash and supply oxygen to promote the initial propagation of the yeast.

However, it should be emphasized that the mash should not be over-stirred, as it will promote the production of acetic acid and detract from alcohol production. Gently stirring a few times each day will bring the yeast, which are not highly mobile, fresh food to transform into alcohol.

The three primary products of the fermentation process are new yeast cells, alcohol, and carbon dioxide. The formation of carbon dioxide bubbles in the mash can be used as a gauge to determine how well the first two are proceeding. The carbon dioxide should be vented into the atmosphere or stored and used for other purposes.

After the mash has worked for about 40 hours, there will be a noticeable slowing in the production of carbon dioxide bubbles. This should be an indication that the fermentation process is almost complete. Typically, a 48-hour fermentation period is required by the yeast to convert the sugar in the mash mixture to alcohol. When this happens, the carbon dioxide bubbling will almost completely cease. If the bubbling slows prematurely, a pH and temperature check should be made to make sure a pH of between 4 and 4.5 and a temperature of between 80° F and 90° F is still present in the mash.

If so, the mash is probably deficient in a few nutrients, such as nitrogen, phosphorus or potassium. This usually will not happen if grain such as corn or wheat is used as a raw material. However, if it does happen, these nutrients

should be added. A common source of nutrients essential for healthy yeast cultures is malted barley. The malted barley will not only supply the needed nutrients, but will also provide additional enzymes that may be needed.

A 15 percent sugar solution can be converted by brewer's yeast into an 8 to 12 percent alcohol solution. Often, in fermenting a sugar solution, the yeast will die from alcohol poisoning before all the sugar has been consumed. It would be beneficial to test the solution before and after distillation to determine the amount of sugar present and the potential for refermenting the solution after distillation, or its use as a feedstuff. However, if care is used to keep the sugar level in the solution below 20 percent, and **brewer's yeast** is used instead of another variety such as baker's yeast, the alcohol production should end in close approximation with the consumption of the sugar in the solution.

After the fermentation solution has worked for approximately 48 hours, and carbon dioxide bubbling has almost ceased, the solution should be checked for alcohol content with a proof hydrometer. If the reading is satisfactory and indicates the fermentation process has been successfully completed, the solution can be separated with a centrifuge or other separation device sufficient to remove large particles, while allowing the alcohol solution to pass through.

These particles will contain approximately three times the percentage of protein as the original feedstock. In addition, unused starch, dextrins, vitamins and fats will be contained in the residue. This residue is called Distillers Wet Grains (DWG), or Distillers Dried Grains (DDG), when the material has been dried. This material makes an excellent feed for cattle and swine, and has potential for being processed into poultry feed, as well as other types of animal feed.

After the grain has been removed from the fermentation solution, the solution will be ready for distillation. In fact, the Distillers Grains can be left in the solution while the distillation process is taking place, if the distilling system used is designed to accommodate them. Higher yields of alcohol are reported when leaving the DWG in the mixture until after distillation.

DISTILLATION

Although there are many different designs for alcohol-producing stills, they all operate on the same principles. One key definition to remember is that of distillation. Distillation is the separation, splitting apart or isolation of two or more compounds by vaporizing them.

In the case of an alcohol and water mixture, such as fermented beer, distillation can be used because the two liquids have different boiling points. That is, water boils at 212° F and alcohol boils at 173° F. Mixtures of alcohol and water boil at varying temperatures between 212° F and 173° F, depending on the ratio of the two liquids in the mixture.

If the solution of 15 percent alcohol and 85 percent water is heated to a boil in an open container, the vapors given off by the solution will contain a larger amount of alcohol than water. As this happens, the percentage of alcohol in the pan will decrease. Continuation of this process will cause the percentage of alcohol in the vapors to drop because of the lower alcohol concentrations in the pan. From this, it can be seen that, as the distillation process begins, a higher proof alcohol will be produced than that produced near the end of the distillation process.

An average distillation run using a simple cooker and condenser will produce 80 to 140 proof alcohol. This alcohol will not be a quality

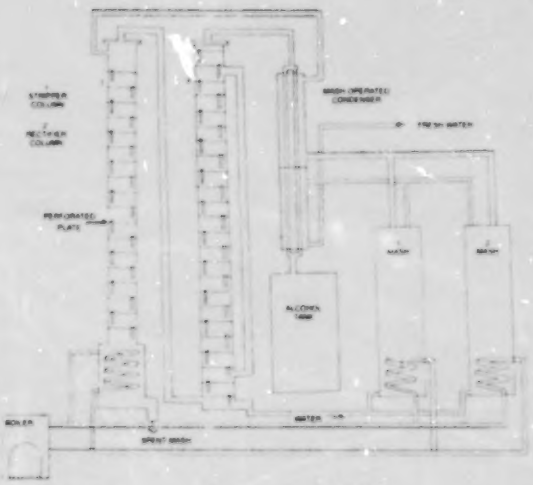


FIGURE II
ALCOHOL PLANT SCHEMATIC

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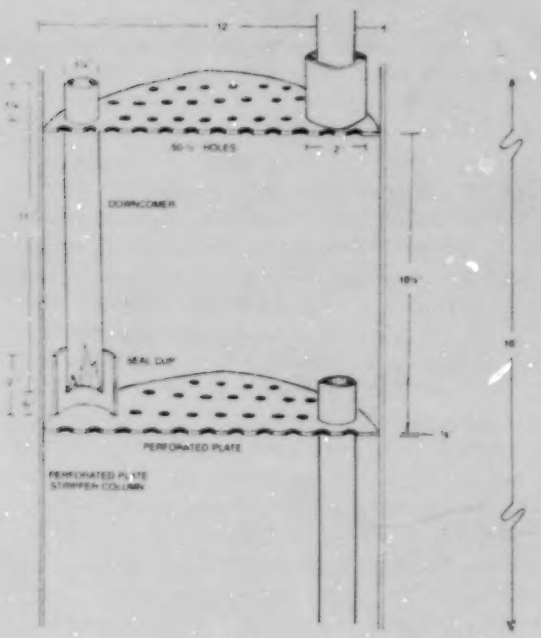
FIGURE III
PERFORATED PLATE COLUMN



sufficient for motor vehicle use. Therefore, additional sophistication must be added to the distilling system in order to increase the proof. Moonshiners have used additional pots and condensers, distilling the product of the first still a second or third time, in an effort to increase the proof of their product. While this technique works fairly well, it is extremely energy-intensive and will wind up using many times the energy contained in the final product.

A more efficient system for vaporizing, condensing and revaporizing the mixture is to use what is known as a pipe column. Such a still can be designed for continuous operation and continuous high proof production without a declining alcohol concentration toward the end of the run. The perforated plate column is a typical, fairly efficient and simple-to-construct pipe column still. However, a steady state operation must be maintained with a constant minimum pressure or the liquid will dump through to the bottom of the column and out the spent mash drain. At proper temperature and pressure, the vapors will flow through holes in the plates and be cooled, thus causing water to condense and flow back down the column through the downcomer pipes, while the alcohol-enriched vapors continue upward.

Construction of a system such as this, capable of producing 20 gallons of 180-190 proof ethanol per hour, should begin with two pieces of thin-wall tubing approximately 12 inches in diameter and 16 feet in length. Next, 18 metal plates the same diameter as the inside of the tubing should be constructed from ¼-inch metal. These plates should have between 50 and 57 holes, one-half inch in diameter, drilled in them. This will give them a ratio of between eight and ten percent of the surface area of the plates. These plates should be evenly spaced throughout the inside of the first 16-foot pipe. Each plate should also be equipped with a 1¼-inch downcomer that extends 1¼ inch above the plate. This downcomer should extend downward to within ¾ inch of the next plate and have a two-inch seal cup at its bottom. This downcomer forms a safety bypass for steam and beer vapor, in case the holes in the plate become plugged. The seal cup forms a liquid seal to keep the heated vapor from using the path of least resistance. The downcomer also acts as a downward flow passage for condensed liquid (which should be mostly water).

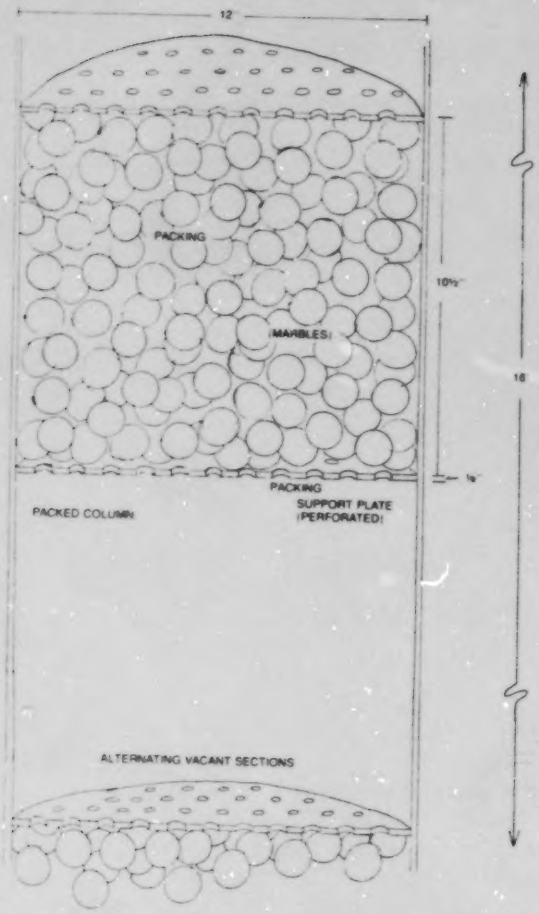
For the second 16-foot pipe, 24 plates ¼-inch thick and the diameter of the inside of the pipe should be made. These plates should have 490 to 520 holes, with a diameter of 5/32 of an inch. The plate should be evenly spaced in the column and have a 1¼-inch downcomer that extends 1¼ inch above the plate and downward to within ¾ of an inch of the next plate and have a two-inch seal cup at its bottom.

From the top of the first column, a four-inch thinwall tube should lead to the bottom of the second column. The first column (stripper column) should be equipped with a port at its bottom large enough for cleaning out any residue that will accumulate in the column. Temperature and pressure gauges should be located at the top, mid-point and bottom of each column.

The second column (rectifier column) should be equipped with a reflux line to return a part of the vaporous material from near the top of the column to the bottom for redistilling. This will increase the proof of the final product.

Both columns should be equipped with 15 PSI safety valves. If the source of heat used to distill the alcohol is steam, the boiler should

FIGURE IV
PACKED COLUMN



also be fitted with appropriate safety valves. The steam should enter the bottom of the stripper column in a heat exchanger at approximately 15 PSI. The temperature near the bottom of the column should, consequently, be between 215° F and 220° F. The mid-point temperature of this column should be around 212° F, while the temperature gauge near the top should read 195° F. The temperature readings on the rectifier column should vary from around 190° F at the bottom to 173° F at the top.

The beer feed pipe can be used to operate a primary condenser from the vaporous product coming from the rectifier column. A temperature gauge on the product line is needed to indicate how much of the product may be escaping as vapor. The product should be cooled to between 60° F and 100° F, but for best results should be as close to 60° F as possible.

The alcohol concentration in the condensed product should be checked frequently to assure things are working well. Alcohol concentrations of 190 proof or better should be obtained if the system is working properly.

If the temperature in the column gets too high, it can be lowered by increasing the beer feed rate. This will also have the effect of supplying more beer to the primary condenser to cool the alcohol vapors.

MODIFYING AN AUTOMOBILE ENGINE TO USE ETHANOL

Alcohol has been used for a number of years as a motor fuel. In fact, it has been successfully used longer than gasoline. The Otto cycle, the first practical internal combustion engine, developed by Nikolaus Otto in 1877, ran on alcohol. Automobiles have run on alcohol at various times in our history, ever since that time. Manufacturers have offered vehicles with optional gasoline or alcohol fuel systems in the past.

Alcohol is an excellent fuel for at least three reasons. The first is its high octane rating (approximately 106), which helps prevent premature detonation (engine knock) under load. The second reason is that it burns cleaner than gasoline and helps prevent gum and varnish build-up in the engine. Finally, alcohol-powered engines run cooler than gasoline engines, which extends engine life.

The octane number given automotive fuels is an indication of the fuel's ability to resist premature detonation within the combustion chamber. Premature detonation comes about when the fuel/air mixture ignites spontaneously because of intense heat and pressure within the compression chamber. Ideally, the fuel would not detonate until the piston reached the proper place for the ignition system to ignite the fuel. Even though gasoline engines typically have a lower compression ratio today than they did ten years ago, detonation is a greater problem now than it was then. This has been caused primarily by the reduced octane

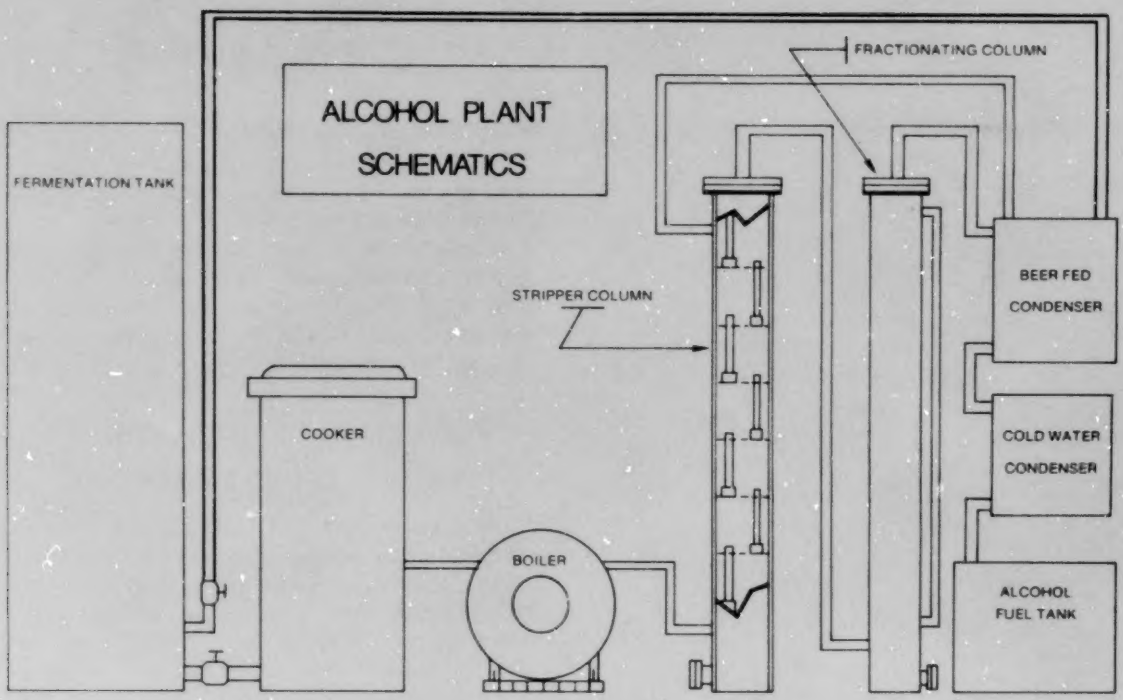


FIGURE V

level of today's gasoline.

A high compression ratio in an engine results in more power per stroke, greater efficiency and better economy. A fuel that resists premature detonation under high compression is desirable. On the average, alcohol is 16 points higher on the research octane scale than regular gasoline.

This higher octane rating is generally cited as the reason most engines perform better with alcohol-gasoline blends or with straight alcohol, after the motor has been properly converted.

The heating value of a fuel is often pointed to as a measure of the amount of energy that can be obtained from the fuel. Since alcohol (84,000 Btu/gal) contains only about 65 percent of the heating value of gasoline (125,000 Btu/gal), it has been said that gasoline will deliver far more energy than alcohol.

However, since the object of an internal combustion engine is to create an explosion, the heating value difference between gasoline and alcohol becomes less significant than if the object were to fire a boiler.

Alcohol's lower Btu level actually helps an engine run cooler. In fact, its lower Btu value, coupled with the fact that alcohol absorbs about 2.5 times the heat that gasoline absorbs, as it is vaporized in the carburetor and engine block, causes an engine to run some 20° F to 40° F cooler than the same engine running on gasoline.

Running an engine on alcohol fuel also has beneficial effects on the environment. Tests have shown that alcohol-powered vehicles emit 95 percent less carbon monoxide and 87.5 percent less hydrocarbons. The tests were run with catalytic converters in place. These figures should be considered within the range of normal test results on alcohol-powered vehicles.

While it is not necessary to have pure alcohol to power a vehicle, alcohol that contains more than 20 percent water will probably cause engine hesitation and rough idling. Alcohol requires a richer air/fuel ratio than gasoline. This richer mixture is not proportionate with

TABLE II

PROPERTIES OF GASOLINE, ETHANOL, AND METHANOL

	Gasoline	Ethanol	Methanol
Chemical Formula	Complex	C_2H_5OH (CH_2CH_3OH)	CH_3OH
Molecular Weight	Complex	46.07	32.04
Carbon to Hydrogen Weight Ratio	5.25:1	4.00:1	3.00:1
Carbon, % by Weight	84.00	52.14	37.48
Hydrogen, % by Weight	16.00	13.12	12.58
Oxygen, % by Weight	0	34.74	49.94
Boiling Point, ° F at 1 Atmosphere	90 to 410	173.3	148.1
Freezing Point, ° F at 1 Atmosphere	-65 to -161	-174.6	-144.2
Latent Heat of Vaporization, Btu/lbs. at Boiling Point and 1 Atmosphere	141.00	378.13	481.00
Latent Heat of Vaporization, Btu/lb. at 77° F and 1 Atmosphere	147.30	395.00	503.30
Heat of Combustion (Heating Value) at 77° F Lower Heating Value, Btu/lb.	19,000	11,550	8,600
Weight per Gallon, lb.	5.84	6.60	6.64
Specific Gravity at 60° F	0.745	0.794	0.796
Flash Point	-45° F	56° F	53° F
Ignition Temperature	740° F	686° F	878° F
Optimum Air/Fuel Ratio	15:1	9:1	6.5:1
Tolerable Air/Fuel Ratios, Rich to Lean	13.2:1 to 71.4:1	5.2:1 to 23.3:1	2.8:1 to 13.6:1
Octane Number, Research	90	106	106
Maximum Desirable Compression Ratio, Int. Comb. Engine, Spark-Ignition Type	8.5:1	15:1	15:1

respect to increased fuel consumption. This is due, at least partially, to alcohol's higher octane rating. Also, because of the higher octane rating, an alcohol-powered vehicle can maintain its fuel economy under loaded vehicle conditions better than its gasoline counterpart.

The method typically used to produce the richer fuel-to-air-ratio is to increase carburetor jet orifice size. The main metering jet orifice size is one of the first things which must be changed. This orifice's size and regulation determines how rich or lean the air/fuel ratio will be when operating a vehicle under cruising conditions. Typically, an enlargement of this office area by 23 to 28 percent will be sufficient to enrich the fuel/air ratio enough to allow the engine to run successfully on alcohol. However, several different jet orifice sizings may need to be tried before settling on the best orifice size for a particular automobile. An auto repair manual will be a handy tool to have while attempting this and the other changes necessary for successful alcohol fuel conversion. After the conversion has been completed, be sure to periodically check spark plugs for an accumulation of white ash. This is an indication that the fuel/air mixture is too lean and is causing the engine to run hot.

The second change needed in the motor's carburetion system is to alter the idle jet orifice size. This jet controls carburetion at low and idle speeds and will probably also have to be enlarged to accommodate alcohol fuels. In some engines, merely backing the idle screw adjustment out will allow enough alcohol into the engine for proper idling. However, if this is not possible, the idle jet orifice should be bored out to an area approximately 25 to 40 percent greater than it occupies while using gasoline.

If the motor being converted has a power valve in its carburetor, this valve should also be enlarged to accommodate the additional alcohol needed to provide a richer fuel/air mixture under accelerating conditions. Usually, an increase of approximately 25 percent in the area for this valve will satisfy the conversion requirements.

The acceleration pump on most motors will need to be altered, in order to provide for the very rich fuel/air mixtures needed for starting and initial acceleration. Some accelerator pumps are equipped with adjustable operating rods. For converting this type of accelerator pump, merely lengthening the stroke of the operating rod will usually be sufficient. Other accelerator pumps may have to be replaced with pumps of a larger capacity.

Alcohol fuel's higher octane ratings give it the ability to withstand increases in ignition timing beyond that of gasoline, without fear of premature detonation. Therefore, in the process of converting an engine from gasoline to alcohol, the ignition timing can be advanced between 5° and 12° further than it could be while running on gasoline. This will improve vehicle performance and not damage the engine, due to premature detonation.

You can only take full advantage of the higher octane rating of alcohol fuel if the engine being converted has a high compression ratio. Because most modern engines have a compression ratio of between 8 to 1 and 8.5 to 1, they will never realize the full performance potential of alcohol fuels. However, certain steps can be taken to increase compression ratios. The pistons in the engine can be replaced with high-compression pistons, which sit higher in the cylinder than regular pistons. This change may need to be accompanied by changing rods and bearings with their high performance counterparts, in order to avoid engine damage.

Another way to increase an engine's compression ratio is with the addition of a turbocharger. This device will pack the air/fuel mixture into the cylinders and thus increase the compression ratio. Maximum compression increases would come at peak RPM conditions and, therefore, would not cause problems with starting.

When an engine is initially altered to use alcohol fuel, certain problems may occur. First, alcohol is a solvent and will tend to loosen and remove the gum and vanish that has accumulated in an engine's fuel system. This gum and varnish will then tend to make its way through fuel lines to the engine fuel filters. These filters may become plugged either partially or completely during the first tank or two of alcohol fuel. Preparation should be made in advance to replace these filters. Many vehicles will have two fuel filters. The first will be a fiber

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TABLE III

Durability of Various Plastics

Alcohols vs. Gasoline

Plastic	Ethanol	Methanol	Gasoline
Conventional Polyethylene	Good	Excellent	Poor
High-Density Polyethylene	Excellent	Excellent	Good
Teflon	Excellent	Excellent	Excellent
Polypropylene	Good	Excellent	Fair
Polymethylpentene	Good	Excellent	Fair
Polycarbonate	Good	Fair	Fair
Polyvinyl Chloride	Good	Fair	Poor

filter on the fuel line, just before it reaches the carburetor. The second filter is usually metal and will be located inside the carburetor at the point where the fuel line connects to the carburetor.

Additional problems may develop as a result of alcohol's solvent capacities interacting with and dissolving some of the plastic or rubber fuel system parts. Neoprene or metal parts can be used to replace these parts, should trouble arise. See Table III.

FEDERAL REGULATIONS

The production of alcohol is regulated by several government agencies, primarily the Bureau of Alcohol, Tobacco and Firearms (BATF). The BATF Regional office for Arkansas and the Southwest Region is located in Dallas, Texas. Inquiries should be addressed to:

Regional Regulatory Administrator
Bureau of Alcohol, Tobacco and Firearms
Main Tower, Room 345
1200 Main Street
Dallas,Texas 75202

In addition, the BATF Southwest Regional Office has a toll-free number:

1-800-527-9380

which can be used to obtain information regarding federal alcohol regulations.

The following is a reprint of information prepared by the BATF, regarding permits for alcohol fuels.

ALCOHOL FUELS AND ATF

The Bureau of Alcohol, Tobacco and Firearms is responsible for administering the laws in the Internal Revenue Code which relate to distilled spirits (alcohol).

THE LAW

a. The Internal Revenue Code of 1954, 26 U.S.C. 517 states: "Every person shall, before commencing . . . the business of a distiller . . . make application for and receive notice of the registration of his plant."

b. "Every person required to file for registration . . . shall, before commencing any . . . operations, apply for and obtain a permit . . ."

DISTILLED SPIRITS

The Internal Revenue Code (26 U.S.C., Section 5002) defines distilled spirits as that substance known as ethyl alcohol, ethanol, or spirits or wine, including all dilutions and mixtures thereof, from whatever source or by whatever process produced . . .

APPLICATION FOR DSP PERMITS

The law provides for two types of distilled spirits plant (DSP) permits. The operating permit authorizes alcohol to be produced for sale or any nonexperimental purpose. The experimental DSP permit authorizes

experimentation and development of distillation and industrial uses of alcohol. The experimental DSP permit does not authorize the sale of alcohol.

Qualification of a DSP for an operating permit is an extensive procedure which requires preparation of numerous forms and investigations to determine whether operation of the DSP can be legally approved.

Qualification for an experimental DSP, which would authorize production of alcohol for personal fuel use, not for sale, is a more abbreviated process. There are no prescribed application forms. Write to the Regional Regulatory Administrator for the region where the plant is to be located. State your name, address and telephone number.

Your letter must completely describe:

1. All land, buildings, and equipment (stills, vats, tanks) to be used in producing alcohol.

2. The planned uses of the alcohol (e.g., heating fuel, lawnmower or other engine fuel, etc.)

3. The property on which vehicles using the alcohol as fuel will be operated. You may describe the portion of your property where the experimental plant will be located by a drawing.

4. The process you will use to produce alcohol including feedstocks, yeasts, enzymes, and distillation method.

5. How you will dispose of the solid and liqud waste from the plant.

6. The type of security you will use to protect the alcohol you produce, from theft or other unauthorized removal from your premises.

Include in your letter application an estimate of the amount of alcohol you intend to produce during a period of 15 days.

If your application to operate an experimental plant is approved, you will need to file a distiller's bond with ATF to cover the liability to federal tax on the alcohol you produce. You may file a $100 cash or surety bond if you will produce not more than 2,500 gallons of alcohol a year. Cash should be converted to a cashier's check or postal money order and made payable to Internal Revenue Service. The bond form, ATF F 2601, may be obtained from the regional office.

Alcohol produced may be used only at the plant premises (i.e., land you describe in your application where alcohol will be produced and used). None of the alcohol may be sold or given away. Any alcohol removed from your plant premises must either be taxpaid or completely denatured in accordance with one of the formulas in this booklet, or made unfit for beverage use by a process approved by ATF. Under existing law, it is illegal to remove alcohol which is fit for beverage use from your premises unless the federal tax on alcohol has been paid.

A permit or authorization issued by ATF does not relieve you of responsibility for complying with any state and local requirements concerning the production and use of ethyl alcohol.

SPECIFIC REGULATORY REQUIREMENTS

Applicable Excerpts From 27 CRF Part 212—

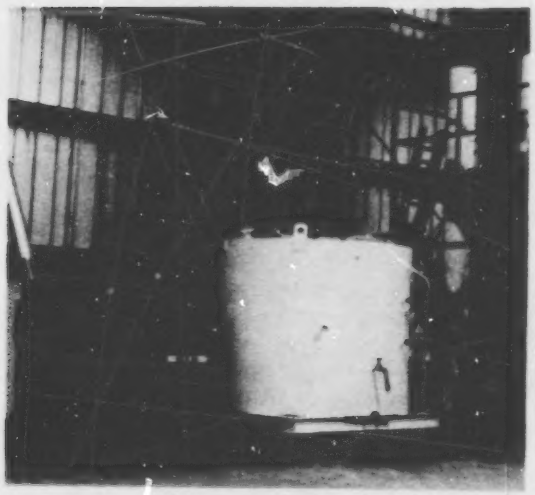
Formulas for Denatured Alcohol and Rum:

Subpart C — Completely Denatured Alcohol Formulas

212.10 General

Completely denatured alcohol will

be denatured in accordance with formulas prescribed in this subpart. Producers of completely denatured alcohol may be authorized to add a small quantity of an odorant, rust inhibitor or dye to completely denature alcohol. Any such addition may be made only on approval by the Director. Request for such approval shall be submitted to the Director in triplicate. Odorants or perfume materials may be added to denaturants authorized for completely denatured alcohol in amounts not greater than 1 part to 250, by weight: PROVIDED, That such addition shall not decrease the denaturing value nor change the chemical or physical constants beyond the limits of the specifications for these denaturants as prescribed in subpart E, except as to odor. Proprietors of distilled spirits plants using denaturants to which such odorants or perfume materials have been added shall inform the Director of the names and properties of the odorants or perfume materials so used. (22 FR 1330, Mar. 1, 1957, as amended by T.D. 6474, 25 FR 5988, June 29, 1960).



Commercial grade equipment is now becoming available to Arkansas farmers. (photo courtesy of Arkansas Ethanol Corporation.)

212.11 Formula No. 18

To every 100 gallons of ethyl alcohol of not less than 160 proof add:

2.50 gallons of methyl isobutyl ketone;

0.125 gallon pyronate or a compound thereto;

0.50 gallon of acetaldol (b-hydroxybutyraldehyde); and

1.00 gallon of either kerosene, deodorized kerosene, or gasoline.

T.D. 6634, 28 FR 1038, Feb. 2, 1963).

212.12 Formula No. 19

To every 100 gallons of ethyl alcohol of not less than 160 proof add:

4.0 gallons of methyl isobutyl ketone; and

1.0 gallon of either kerosene, deodorized kerosene, or gasoline.

(T.D. 6634, 28 FR 1038, Feb. 2, 1963)

STATE REGULATIONS

There are no provisions in Arkansas beverage control law that give authority to issue a permit for the production of alcohol as a motor fuel. All past experience in this area is with the Alcohol Beverage Control Division (ABC) of the Department of Revenue. As the law now reads, persons manufacturing alcohol that is fit for human consumption must pay a $1,500 distiller's permit fee. The payment of the $1,500 permit fee will not be necessary if one can ensure that the alcohol being produced will be rendered unfit for human consumption at the source of manufacture. If an ABC agent visits your operation and finds that you have consumable, untaxed alcohol, you will be subject to the penalties existing for the illegal manufacture of beverage alcohol.

In an effort to streamline efforts by private concerns in the area of alcohol fuel development, the Arkansas Energy Office sponsored legislation during the 1980 session of the General Assembly that calls for the establishment of an alcohol fuels registry (Act 60 of 1980). This registry will be operated by the

Sweet sorghum yields grain and sugar, both of which can be used as ethanol feedstocks.

state energy office, effective April 1, 1980. All persons operating fuel alcohol manufacturing facilities are required, by this legislation, to register with the Arkansas Energy Office. Information developed by the registration system will be used, among other things, to offset the need for other agencies to become involved in the development of their own regulations governing alcohol fuels, which might adversely affect the alcohol fuels industry.

Here is the entire text of Act 60 of 1980:

ACT 60

1980

For An Act To Be Entitled
"AN ACT TO AMEND CERTAIN PROVISIONS OF ACT 255 OF 1979, THE ARKANSAS ENERGY REORGANIZATION AND POLICY ACT OF 1979, FOR THE PURPOSE OF AUTHORIZING THE ARKANSAS DEPARTMENT OF ENERGY TO ESTABLISH AND MAINTAIN A STATE ALCOHOL FUELS PRODUCTION REGISTRY AND FOR OTHER PURPOSES."

BE IT ENACTED BY THE GENERAL ASSEMBLY OF THE STATE OF ARKANSAS:

SECTION 1. Section 4(B) (2) of Act 255 of 1979 (Ark. Stat. Ann. 5-934 (B) (2) is hereby amended to add the following subsection:

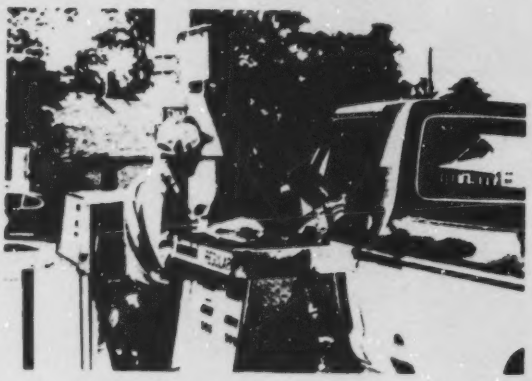
"(i) Establish, maintain, and promulgate rules and regulations for the purpose of administering a state alcohol fuels production registry, and to require all persons manufacturing either fuels containing alcohol or alcohol for use in or as fuel to register with the Department. The Department shall cooperate with the State Alcohol Beverage Control Commission and its Enforcement Division by furnishing them with any information that they may request from the Registry."

SECTION 2. SEVERABILITY CLAUSE. The General Assembly hereby declares that each of the sections and provisions of this Act are severable, and in the event that any one or more of such sections are declared unconstitutional or invalid, the remaining sections and provisions of this Act shall remain in effect.

SECTION 3. REPLACING CLAUSE. All laws and parts of laws in conflict with this Act are hereby repealed.

SECTION 4. EMERGENCY CLAUSE. It is hereby found and determined by the General Assembly that a national energy crisis exists and that it calls for action by the States to stimulate the production of alternative fuels as substitutes for oil and imported petroleum products. It is further found that the creation of a state alcohol fuels production Registry to be administered by the State Department of Energy would facilitate the rapid development of production capability for such fuels by providing a simple procedure for collecting information that may be necessary to ensure the proper enforcement of the alcoholic beverage control laws of the State. Therefore, an emergency is hereby declared to exist and this act being

necessary for the immediate preservation of the public peace, health, and safety, shall be in full force and effect from and after its passage and approval.



Anhydrous ethanol can be blended with gasoline for direct use in unmodified vehicles.

SELECTED BIBLIOGRAPHY

Crombie, Lance. *Making Alcohol Fuel, Recipe and Procedure*. Rutan Publishing, 1979. Post Office Box 3585, Minneapolis, Minnesota 55403.

Mother's Alcohol Fuel Seminar. **The Mother Earth News**, 1979. P.O. Box 70, Hendersonville, North Carolina 28739.

Fuel From Farms. U.S.D.O.E./SERI/SP-451-519-UC-61, 1980. Available from: National Technical Information Service (NTIS), U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

Alcohol Fuels and ATF. Department of the Treasury, 1979. Available from: Regional Regulatory Administrator, Bureau of Alcohol, Tobacco, and Firearms, Main Tower, Room 345, 1200 Main Street, Dallas, Texas 75202.

APPENDIX A

CONVERSION FACTORS

MULTIPLY	BY	TO OBTAIN
Acres	43560	Square Feet
Atmospheres	14.696	Pounds/square inch
Bags Cement	94	Pounds of Cement
Barrels (U.S. Dry)	4.083	Cubic Feet
Barrels (U.S. Liquid)	4.211	Cubic Feet
Barrels (U.S. Liquid)	31.5	Gallons
Barrels (Oil)	42	Gallons
Boiler Horsepower	33475	Btu (mean)/hour

MULTIPLY	BY	TO OBTAIN
Boiler Horsepower	34.5	Pounds of Water Evaporated from and at 212° F per hour
Btu (mean)	251.98	Calories, gram (mean)
Btu (mean)	0.29305	Watt-hours
Btu (mean)/pound	0.556	Calories, gram (mean)/gram
Bushels (U.S.)	1.2444	Cubic Feet
Calories, Gram (mean)	3.98685×10^{-3}	Btu (mean)
Candle Power (Spherical)	12.566	Lumens
Centimeters	0.3937	Inches
Cubic Centimeters	3.531445×10^{-5}	Cubic Feet
Cubic Feet	1728	Cubic Inches
Cubic Feet	7.48052	Gallons
Cubic Foot of Water	62.37	Pounds
Cubic Inch	16.387162	Cubic Centimeters
Cubic Yards	0.76456	Cubic Meters
Gallons	231	Cubic Inches
Gallons	128	Ounces (Fluid)
Horsepower	2545.08	Btu (mean)/hour
Horsepower	550	Foot-Pounds/second
Inches	2.54000508	Centimeters

MULTIPLY	BY	TO OBTAIN
Kilowatts (Abs.)	1.341	Horsepower
Meters	3.280833	Feet
Miles	5280	Feet
Parts Per Million	0.058417	Grains/gallon
Pounds of Water Evaporated at 212° F	970.3	Btu
Proof	0.5	Percent Alcohol by Volume
Watts (Abs.)	3.41304	Btu (mean)/hour

Note: Appendices B through G are meant to serve only as starting points for people interested in pursuing the production of alcohol fuels. These lists are not meant to be all-inclusive nor does inclusion of an individual or firm imply an endorsement by the Arkansas Energy Office.

APPENDIX B

PEOPLE/FIRMS PRESENTLY DESIGNING OR MANUFACTURING SMALL ALCOHOL PLANTS

Roy Gentry
Riddick Engineering Corp.
Consultants
2310 First National Bank Bldg.
Little Rock, AR 72201
Phone: 501-374-9219

John Pate
Environmental Enterprises
423 North University Avenue
Little Rock, AR 72205
Phone: 501-664-3983

Dr.Carl Wenby
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Brookings, SD 57006
Phone: 605-688-4116

Dr. Robert Chambers
ACR Process Corp.
602 East Green Street
Champaign, IL 61820
Phone: 217-384-8003

Alan Ziethamer
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Alexandria, MN 56308
Phone: 613-763-7392

Malcolm Lillywhite
Domestic Tech. Institute
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Evergreen, CO 80439
Phone: 303-674-1597

Farm Energy Systems
P.O. Box 2573
Pocatello, ID 83201

APPENDIX C

ALCOHOL-MANUFACTURING ENGINEERING FIRMS

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Consultants
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Environmental Enterprises, Inc.
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1625 West Belt North
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Phone: 312-454-3685

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Cincinnati, OH 45219
Phone: 513-281-2800

Mr. Jim Kaumana
Raphael Katzen Assoc.
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Cincinnati, OH 45208

William J. Jones
Day & Zimmerman, Inc.
1818 Market Street
Philadelphia, PA 19103
Phone: 215-299-8193

Mr. Jackson Yu
Bechtel Corp.
50 Beale Street
15th Floor-Room B15
San Francisco, CA 94119
Phone: 415-768-1234

Chemapec, Inc.
230 Crossways Park Drive
P.O. Box 35445
Woodbury, NY 11797
Phone: 516-364-2100

T.D. Striggles
PEDCO International
Chester Towers
11499 Chester Road
Cincinnati, OH 45246
Phone: 513-782-4500

APPENDIX D

LABORATORY SUPPLIES AND EQUIPMENT

Rascher & Betzold, Inc.
5410 North Damen Avenue
Chicago, IL 60625
Phone: 312-275-7300

Sargent-Welch Scientific Co.
5915 Peier Street
Dallas, TX 75235
Phone: 214-357-9381

Miles Laboratories
Marshall Division
P.O. Box 932
Elkhart, IN 46515
Phone: 219-262-7176

APPENDIX E

ENZYME SUPPLIERS

Big D & W Refining and Solvents Co.
P.O. Box 1516
Van Buren, AR 72956

BIOCON, Inc.
216 Midland Avenue
Lexington, KY 40507

Norbert Haverkamp
Compost Making Enzymes
Rural Route 1, Box 114
Horton, KS 66439
Phone: 913-486-3302

Miles Laboratories
Marshall Division
P.O. Box 932
Elkhart, IN 46515
Phone: 219-262-7176

Rohm and Haas Company
Independence Mall West
Philadelphia, PA 19105

Novo Laboratory, Inc.
59 Danbury Road
Wilton, CT 06897
Phone: 203-762-2401

Aquaterra Biochemicals Corp.
P.O. Box 496
Lancaster, TX 75146
Phone: 214-227-6960

Scientific Products Co.
North Kansas City, MO 64116
Phone: 816-221-2533

APPENDIX F

YEAST SUPPLIERS

Anhaeuser-Busch (Warehouse)
1900 East 15th Street
Little Rock, AR 72202
(Baker's Yeast Only)
Phone: 501-372-5168

Big D & W Refining and Solvents Co.
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Van Buren, AR 72956

BIOCON, Inc.
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APPENDIX G

SOURCES OF PUBLIC FINANCING

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Technology Assistance Div.
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and Development
National Science Foundation
Washington, D.C.20550
Phone: 202-634-4017

Dr. J.E. Snell
Office of Energy Programs
Natl. Engineering Lab.
Natl. Bureau of Standards
Dept. of Commerce
Washington, D.C. 20234
Phone: 301-921-3275

Leland Duncan
Chief of Community Program
U.S. Farmers Home Administration
P.O. Box 2778
Little Rock, AR 72203

Arkansas Energy Future

Methane

INTRODUCTION

The continued displacement of energy prices has caused individuals and organizations in all parts of the country to look at the potential for developing sources of energy that can be derived from renewable resources. One energy system that uses renewable resources as a feedstock and appears to have a great deal of potential for development in rural parts of Arkansas is anaerobic digestion.

By means of the anaerobic digestion process, a methane-rich biogas can be produced that can be substituted for natural gas, liquified petroleum gas or other stationary-use fuels. There are also substitutions that can be made for mobile fuels; however, a number of technical problems still exist, which severely restrict the development of this application.

While the energy consumed in the production of agricultural goods represents no more than three to five percent of our overall national energy use, this small amount of energy is of great significance to the national economy and the health and welfare of the entire country. The amount of energy consumed in agricultural production is of great significance, as is the ready availability of that energy at critical times in the agricultural production cycle. For instance, it would be of little value for a broiler producer to have an abundant supply of fuel one week after a majority of his new supply of baby chicks had frozen and/or smothered to death due to a lack of fuel.

It is for reasons such as this that the agricultural community must be provided with a ready supply of energy and at a price that will allow its use. The development of methane-producing anaerobic digestion systems is one means of assuring agricultural enterprises that they will be self-sufficient in the face of interrupted conventional energy supplies.

THE ANAEROBIC DIGESTION PROCESS

The anaerobic digestion process can be defined as the breakdown of organic matter by a microbial population that lives in an oxygen-free environment. This process converts organic material to a combustible gas and to an effluent, which retains a vast majority of the nutrient value of the original raw material.

Anaerobic digesters can be used to recover energy from organic material, act as a partial waste-treatment system, and stabilize the nutrients in organic material, making them more readily available for plant development. The effluent may not be discharged into waterways; however, it may be spread on fields and pastures as a fertilizer without the odor problems associated with the spreading of raw manure.

The biogas produced consists of approximately 60 percent methane and 40 percent carbon dioxide, as well as traces of other gases. Close to 20 percent of the gas produced in the summer and 30 percent of the gas produced in the winter can be used to provide the process energy requirements of the anaerobic digestion process.

MICROBIOLOGY

The anaerobic digestion process converts the cellulose, starch, fats and proteins in organic materials to methane and carbon-dioxide gases. The first phase, hydrolysis, is a liquefac-

tion step, converting insoluble fats, proteins and carbohydrates to soluble compounds such as glucose, glycerol and amino acids, long-chain fatty acids and peptides.

These materials are converted in the second phase of the process by acid-producing bacteria to volatile and fatty acids, carbon dioxide, hydrogen and alcohols.

In the third phase, these materials are converted by substrait-specific methanogenic bacteria to dissolve methane and carbon-dioxide gases. From the dissolved stage, the gases undergo phase transfer from liquid to gas, and biogas is evolved.

An anaerobic digestion system's design should provide optimal conditions for microbial growth and enzymatic reactions. The selection of an appropriate feedstock, process design and the method in which the system is operated are all important factors in the success of the digestion system.

FEEDSTOCK SELECTION

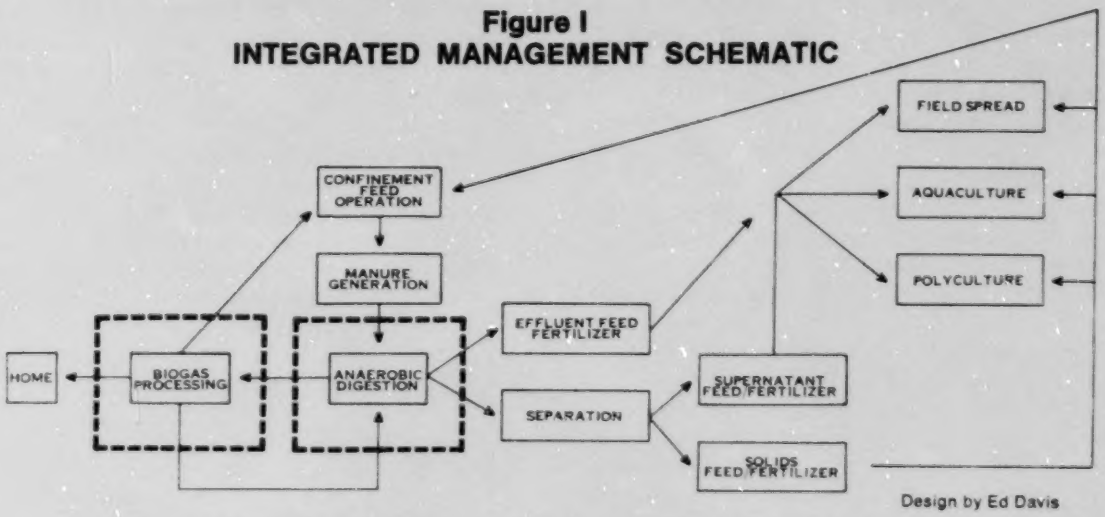
Biogas can be produced from virtually any organic matter containing a slight nutrient availability. However, the chemical and physical composition of the feedstock will have a major impact on its digestibility and the amount of gas that will be produced.

Plant material is the most abundant of all potential feedstocks for an anaerobic digester. Cellulose is the major component of plant matter and in its free form, it is normally digested easily. However, cellulose is often found in a form that is bound up in lignin, a material that is inert to the bio-chemical reactions occurring in the anaerobic process. Therefore, care must be exercised in selecting a cellulosic-based feedstock for digestion.

Animal wastes, some food-processing wastes, aquatic plants and some grasses generally make the best feedstocks for anaerobic digestion. This is because of their high moisture content, high biodegradability, low pre-processing requirements, and concentrated availability.

In addition to feedstock biodegradability, the availability and balance of nutrients, particularly the carbon/nitrogen ratio, is important to digestibility and biogas production. Feedstocks with a carbon/nitrogen ratio in the range of 20:1 to 30:1 are generally considered stable feedstocks, which will not cause an imbalance in the digester. Higher nitrogen levels have had a history of souring the digester, while higher carbon levels have tended to inhibit bacterial growth. However, as more experience is gained with anaerobic systems, it has been found that, under certain circumstance, both ends of this range can be exceeded without causing a great deal of harm. For example, recent work has indicated that the solids loading rate can be varied to

Figure I
INTEGRATED MANAGEMENT SCHEMATIC



Figures II & III are inset (broken lines) on the following schematics.

compensate for problems that might otherwise occur as a result of a higher or lower carbon/nitrogen ratio.

Excessive quantities of various organic or inorganic substances found in a feedstock may cause a toxic influence on anaerobic organisms. It has been reported that ammonia toxicity has resulted at levels from 50 mg/l to 2000 mg/l. However, it has also been found that the micro-organisms can acclimate to varying levels of toxicity for different materials. This acclimation is usually carried out over a substantial period of time, while the normally-toxic material is introduced at low levels and gradually increased to higher levels.

It has been found that some of the antibiotics used in confined animal feeding operation will have a toxic effect on an anaerobic digester. For instance, the antibiotic lincomycin, which is used to treat diarrhea in pigs, is toxic to anaerobic bacteria in concentrations as low as four parts per million.

ANIMAL WASTE

Due to their high moisture and well-balanced nutritional content, animal wastes typically represent one of the most attractive feedstocks for an anaerobic digester. Also, much of the original plant material has been broken down into more simple compounds, which contribute to the ease of digestion.

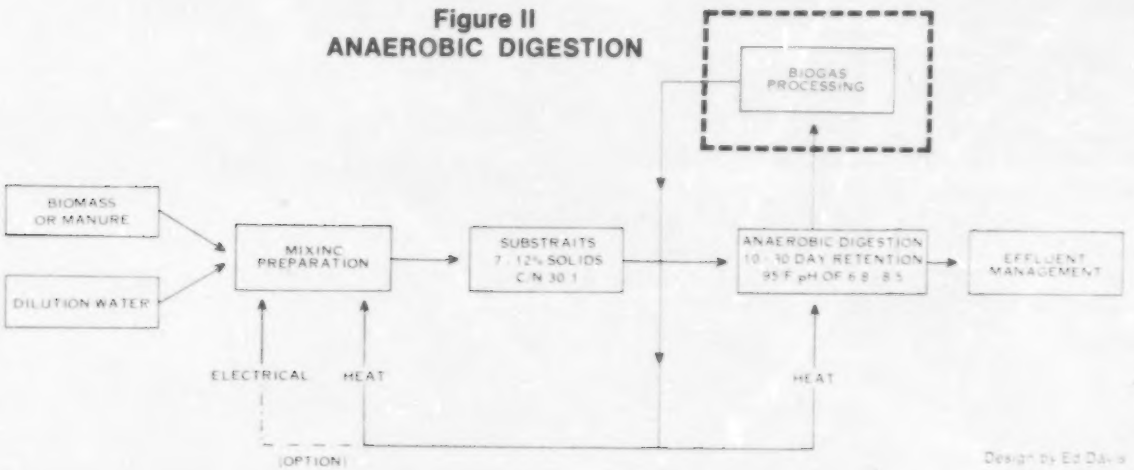
Anaerobic digestion is especially suited to the preservation of manure's soil-conditioning and fertilizing value, while producing biogas. It may also be beneficial to livestock raisers because the digested manure can have a re-feeding value to the producing species or to another. Refeed of digested manures can help stretch feed supplies and allow expansion and increased production on constant feed supplies.

CROP RESIDUE

At least two points need to be examined before a system is designed for the conversion of crop residues to biogas. First, the crop residues are relatively dry matter, with energy values of 5,000 to 7,000 British thermal units (Btu's) per pound. Significant amounts of lignin are present in most crop residues and that makes anaerobic digestion difficult and inefficient. The lignin can be more efficiently used through direct combustion as opposed to digestion.

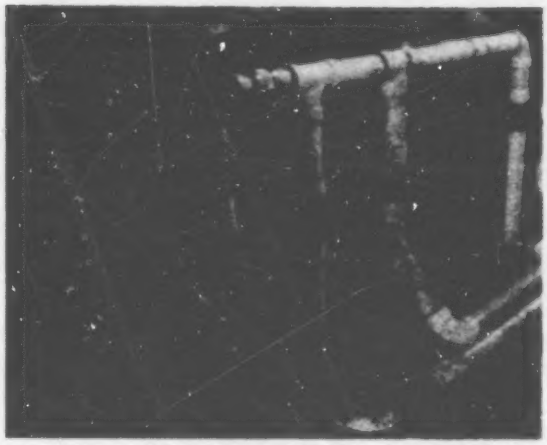
Secondly, in removing the residues from the land, organic matter that may be needed by the soil will be removed. Even though the anaerobic process would preserve most of the nutrient and organic value of the residue, the collection process would require approximately one-third of the energy that would be obtained from digestion. In addition, another 20 to 30 percent of the energy produced would be required to operate the preparation and digestion process.

Figure II
ANAEROBIC DIGESTION



PROCESS REQUIREMENTS

While methane production can occur over a broad range of environmental and operating conditions, optimum gas production will be obtained with different process designs, depending on the substrate used.



Arkansans like Al Bowles of Jasper are finding they can make their own fuel from waste material through anaerobic digesters like this one.

TEMPERATURE

Methane fermentations have been classified into three temperature ranges:

(1) psychrophilic range (under 60° F);
(2) mesophilic (60° — 110° F); and
(3) thermophilic (110° — 150° F).

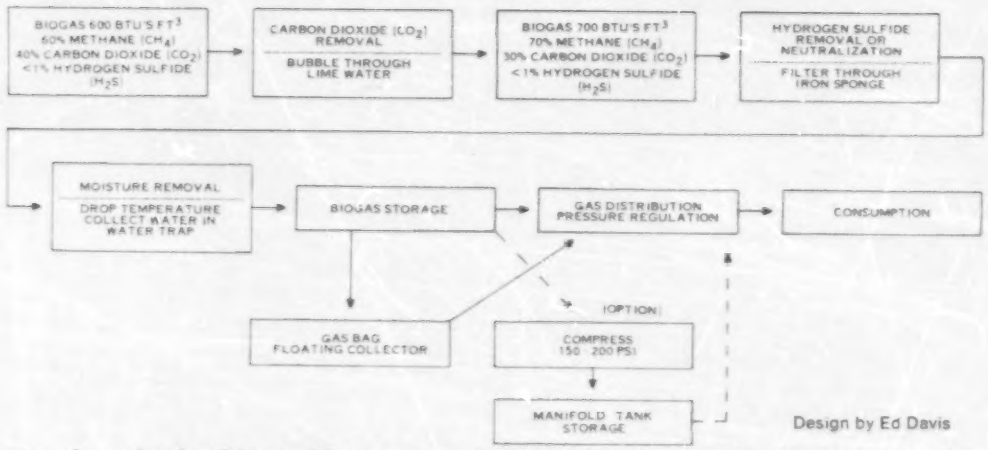
Experience with different temperature ranges has produced varying results. However, it is generally concluded that the higher temperature ranges tend to produce a given volume of gas in a shorter period of time. In addition, there is very little indication that greater amounts of gas can be produced from a given amount of substrate by merely increasing the temperature of the digester. Maintaining a digester at higher temperatures requires additional energy and will have a negative impact on the system's energy balance. The single advantage of operating at high temperatures appears to be the ability to digest larger amounts of substrate in a smaller digester tank.

The micro-organisms are sensitive to thermal shock and, therefore, require relatively stable temperatures within the digester. A variance of no more than three to five degrees from the set temperature is recommended.

pH REQUIREMENTS

Methane-producing bacteria require a neutral to slightly alkaline environment (pH of 6.8 to 8.5). If the acid-forming bacteria reproduce too quickly, the acid level will increase faster than the methane-forming bacteria can consume it, creating an imbalance within the

Figure III
BIOGAS PROCESSING



Entire system is maintained in positive pressure to prevent siphoning of oxygen into system.

system, and consequently, a decrease in methane production. If an imbalance appears to be occurring, lime, sodium bicarbonate or other buffering agents can be added to the system. Usually, however, the methane formers will recover and stabilize the system without assistance.

RETENTION/LOADING RATE

The rate at which substrate is supplied to the digester is called the loading rate. This rate is typically expressed in pounds of solid per cubic foot of tank capacity.

The number of days the material stays in the digester is called the retention time. Most of the research work done in the United States seems to indicate a retention time of 15 to 20 days is preferred. Biogas may be produced for as long as 120 days. However, the cost of retaining the substrate for this period of time cannot be justified by the quantity of gas produced after the 15 to 20-day period.

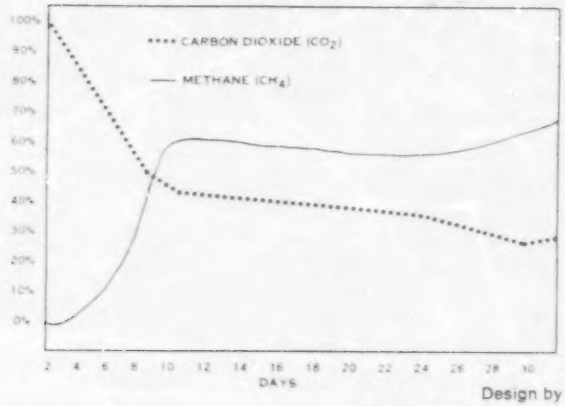
Uniform wastes with higher carbon/nitrogen ratios, such as dairy manure, can be fed at higher solid concentrations than can poultry manure, which has a lower carbon/nitrogen ratio. Higher loading rates have a positive influence on digester economics, due to the lower requirement for tankage and energy to bring the reduced total volume up to operating temperature.

Jim Keel of near Harrison has constructed this earth-sheltered anaerobic digester near his cattle-holding pen.

Turkey, layer, and broiler manure should be fed into the digester at approximately 7 percent solids. Since this manure is typically voided at approximately 25 percent solids, it will be necessary to add 2.5 gallons of water to each gallon of manure or 2.5 pounds of water for each pound of manure fed to the digester.

Dairy and beef cattle manure can be success-

Figure IV
PERCENTAGE OF TOTAL BIOGAS PRODUCED BY BATCH DIGESTION



Design by Ed Davis

As shown in the above representative graph, the percentage of methane contained in biogas increases after a few days, while the percentage of carbon dioxide decreases.

fully digested at a 12 percent solids concentration. This is almost identical to the solids concentration in the manure as the manure is voided. Therefore, no additional water need be added before digestion, unless some drying has occurred.

Swine manure is typically voided with a solids concentration of approximately 10 percent. It is recommended that this material be fed to a digester at approximately 7 percent solids. This will necessitate the addition of one-half pound of water to each pound of solids before it is fed to the digester.

SYSTEM DESIGN

There are a number of different designs that can be used to construct anaerobic digester systems. These range from very simple and labor-intensive systems, such as those used in Asia, to highly-automated wastewater treatment plants. Since a farm system typically will not be operated by a chemical engineer or other highly-technical personnel, the design must be simple, reliable, easy to manage and service. However, the very simple approach used in Asia is probably not acceptable, due to its high labor requirements. A careful balance between initial capital, labor, maintenance and operational costs of the system must be obtained in order to show profitability and practicality.

BATCH SYSTEM

A batch system consists of single or multiple tanks, which receive manure until they are completely filled. They are sealed and allowed to ferment for a period of 15 to 30 days. The effluent is then removed and the tank is refilled to start the process over again. A multitank system can have at least one tank producing gas at all times, while other tanks are being filled. Confined animal feeding systems, such as turkey or broiler farms, which remove manure on an infrequent basis, are the ones most likely to practice batch digestion. However, it is unlikely that many turkey or broiler farms will practice anaerobic digestion, due to the very dry nature of the litter as it is removed from the houses.

PLUG-FLOW SYSTEM

The plug-flow system has a single tank digester and is fed on a frequent and regular basis, usually once each day. After the waste material is mixed and introduced into the digester, it flows through the tank as if it were a big pipe. Plug-flow digesters are particularly suited to high solids concentrations (10+ percent), where the solids will not settle out. The scale does not appear to hinder the use of this type of digester, as it can be used for large or small systems. Mixing systems are not used in plug-flow digesters, and the mixers would

TABLE I

DILUTION FACTORS AND RETENTION TIMES FOR DIFFERENT ANIMAL MANURES

	Percent Solids To Be Run in Digester	Typical Percent Solids as Voided	Amount of Water To Add Per Unit* of Manure (1)	Days of Retention in Digester
Layers	7	25	2.5	30
Pigs—All	7	10	.5	15
Dairy Cows	12	12	0	12
Beef Cattle	11	11	0	12½
Broilers/Turkeys	7	25	2.5	30

*For example, if you are working in gallons, for every gallon of manure, add this many gallons of water. If you are working in pounds, for every pound of manure, add this many pounds of water.

(1) If your manure is not typical and has a higher or lower percentage of solids than shown in the Table, you can calculate how much water to add by the formula:

$$\frac{\text{Percent Solids as Collected} - \text{Percent Solids Run}}{\text{Percent Solids Run}}$$

destroy the integrity of the plug-flow. They would cause solids to be prematurely discharged before optimum digestion had taken place. Plug-flow digesters appear to be particularly suited to dairy operations and to swine and laying operations, where solids settling is not a major problem.

SINGLE-TANK COMPLETE-MIX SYSTEMS

A vertical cylinder tank is usually employed as the digester tank for the single-tank complete-mix system. As the name indicates, a mixing system within the digestion tank is inherent to this type of digester. This system typically is fed on a daily basis, much like a plug-flow system. However, due to the mixing, the effluent that is removed daily contains solids, which have been retained for much shorter periods than the design retention time would indicate. The mixing provides for better microbe-substrate contact and helps prevent scum formation. Comparative testing has led to the conclusion that mixing in systems with less than 100,000 gallons of capacity actually requires more energy than it generates, and in at least one case, it was found that mixing actually reduced gas production.

MULTI-TANK OR PHASE DIGESTERS

Because of the difference in environment that optmizes the microbiological action of the acidification and methanation steps in anaerobic digestion, two tanks may be placed in a series and closely approximate the change between the two phases. Each tank can be controlled separately, so as to optimize the conditions that will promote the step taking place in that tank. Where hydrolysis is the limiting step, the number of tanks can be expanded to three.

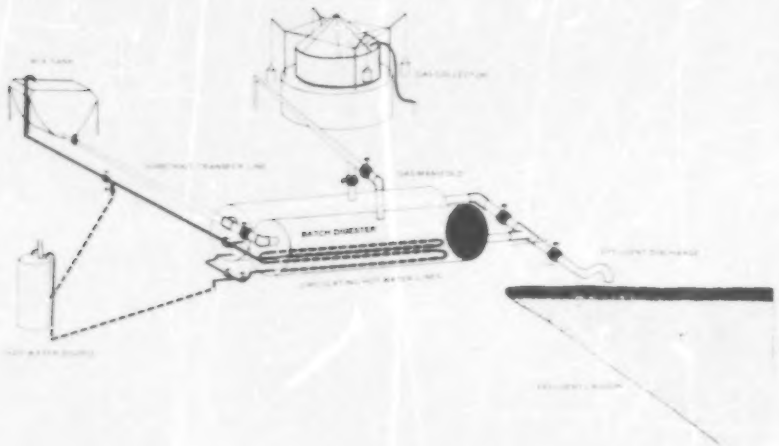
Phase digestion is reported to have the following advantages:

(1) higher loading rates without inhibiting the reactions in other phases;
(2) increased process stability;
(3) greater concentrations of methane in the final gas; and
(4) lower retention times.

ENERGY REQUIREMENTS

The incoming material will use from 80 to 90 percent of the heat required to operate a well-insulated anaerobic digester. Since the influent is usually at or near ambient temperature and the effluent is at digester temperature,

Figure V
MULTIPLE-BATCH DIGESTER



Design by Ed Davis

counter current heat exchangers, which can capture up to 55 percent of the sensible heat of the effluent, can be used to improve the overall energy balance.

Loading high solids will allow a higher gas yield per unit of tank volume. A smaller tank will cut capital costs and lower tank-heat losses. If the need to mix the contents of the digester is eliminated, a good deal of energy can be saved. Also, loading high solids material, such as dairy manure, will eliminate the need to pre-mix, due to the solids' resistance to settling out.

BY-PRODUCTS

The gas produced by anaerobic digestion is approximately 60 percent methane and 40 percent carbon dioxide, with traces of hydrogen sulfide, water vapor and ammonia. This gas is capable of producing 600 Btu/cubic foot, as compared to natural gas, which is capable of producing 1000 Btu/cubic foot. Biogas is an excellent fuel for producing heat or running engines.

Any mixture of biogas and air containing from five to 15 percent methane is considered explosive, and will burn readily when ignited. Biogas is not poisonous but can exclude oxygen from enclosed areas and, thereby, cause suffocation.

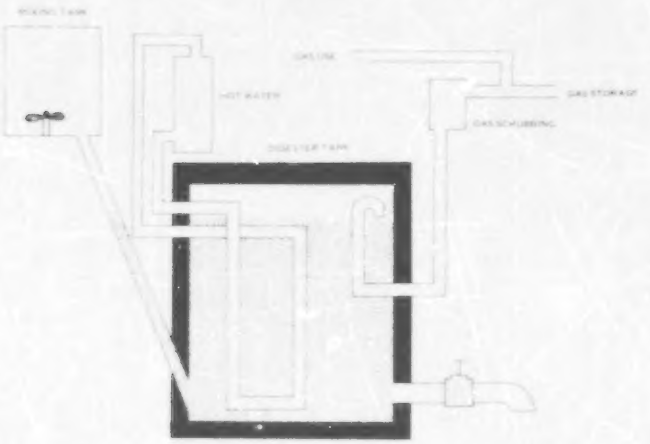
The carbon-dioxide content of the biogas is rarely a problem when producing heat. Engines can be readily modified to use biogas with a substantial CO_2 content. However, the hydrogen sulfide should be removed immediately before storage or use. This should be done to protect burners, tanks or engines from corrosion. Hydrogen sulfide can be easily and cheaply removed with an iron sponge consisting of one bushel of sawdust, 25 pounds of ferrous sulfate, five to six pounds of lime and one pound of iron filings.

BIOGAS PRODUCTION AND STORAGE

A considerable volume of biogas can be produced from the waste of even a medium-size laying or swine operation. For instance, a 20,000-bird layer operation could be expected to produce approximately 6,400 cubic feet of gas per day, while a 150-sow farrow-to-finish operation might produce as much as 5,100 cubic feet of gas per day. See Table III. Since biogas contains about 600 Btu's per cubic foot, it would take 153.3 cubic feet to equal the 92,000 Btu's contained in one gallon of liquefied petroleum gas. A tank at atmospheric pressure would have to have a capacity of over 1,146 gallons to hold enough biogas to replace one gallon of LP gas.

Unlike propane or butane, biogas can be

Figure VI
PLUG FLOW DIGESTER



Design by Alford Drinkwater

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liquefied only at very low temperatures and very high pressures. The gas can be compressed; however, a good deal of the energy produced will be used in this step. It is generally felt that the best method for storing biogas is in flexible membranes. These membranes are typically made from special synthetic materials such as hypolon. Protection from the elements and vandalism must be afforded these storage tanks. Therefore, the storage should be kept to a minimum, in order to minimize costs. This can be accomplished by having a steady demand for the gas with very little fluctuation from hour-to-hour or day-to-day. This is not possible in all cases, so trade-offs will have to be made in altering current gas demands and capitalizing the necessary gas storage to accommodate demand swings. Electrical production potential of a given operation can be obtained by the following method:

First, multiply the total Btu's that can be produced each day by .25. This is the efficiency that can be expected from an engine-generator set constructed to run on biogas.

Next, this figure should be divided by 3,413, which is the number of Btu's in a kilowatt of electricity. This figure should then be divided by 24 hours, in order to determine how many kilowatt hours could be produced on a continuing basis.

A single laying hen will produce sufficient manure to be converted into .32 cubic feet of biogas per day. A 30,000-bird laying operation could produce 9,600 cubic feet of gas per day.

The following formula can be used to show the electric generating potential for this flock of birds.

$$\frac{A \times B \times C \times D}{E} = KW$$

Where:

A = The gas production potential per bird (cu. ft/day)

B = The number of birds (30,000)

C = The Btu content per cubic foot of gas (600 Btu's)

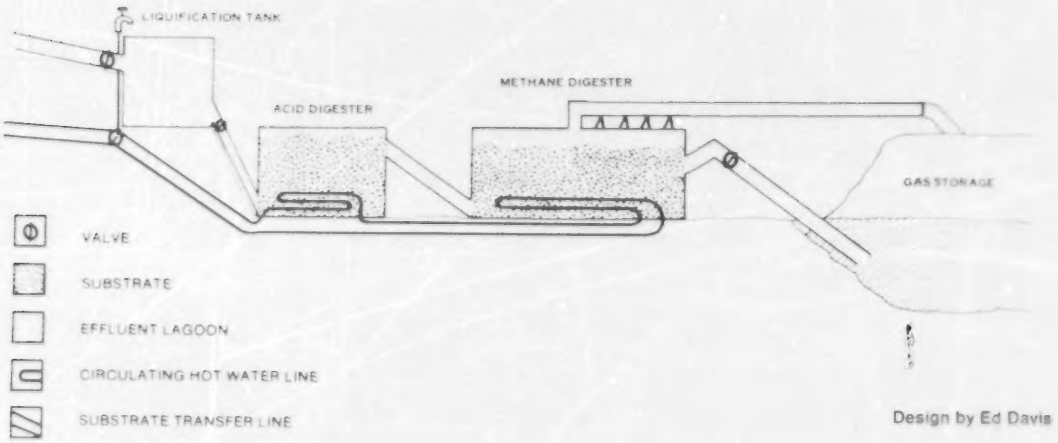
D = Conversion efficiency factor for producing electricity (.25)

E = The number of Btu's in a kilowatt of electricity (3,413 Btu's)

This formula can be applied as follows:

.32 cu. ft. × 30,000 birds × 600 Btu's × .25 ÷ 3,413 Btu's = 422 kilowatts per day.

Figure VII
PHASE DIGESTION SYSTEM



Design by Ed Davis

A 30,000-bird laying operation should, therefore, be capable of producing 422 kilowatts of electricity per day.

EFFLUENT

The effluent from the anaerobic digestion process can be used for fertilizer and soil conditioner or it can be used as a feed supplement for animals. The total solids in the effluent are typically reduced by 25 to 50 percent, depending on the system design. Therefore, the effluent is more easily handled by pumps and other equipment generally used for liquid-waste management. A great deal of organic nitrogen is converted to ammonia and is contained in the liquids. The liquids should be managed carefully, in order not to lose the nutrient content. Knifing the material into the soil is recommended to help prevent volatilization of the ammonia.

Animal refeed of broiler-house waste has taken place for several years, with some sucess. However, due to anaerobic digestion's lack of development, there has been very little actually done in the way of refeeding digester effluent. Suggestions of drying the effluent with belt presses or filters and feeding the recovered solids have been made. It has also been suggested that this effluent could be used to support a fish culture, such as a catfish farm, or it could be used in a hydroponic gardening operation. One thing is certain at this point — the effluent contains valuable nutrients for feeding and/or fertilizing and should be treated with care to assure this value is not wasted.

Methane systems are deductible on individual state income-tax forms — 100 percent — because of the support for alternative forms of energy supplies provided by legislators such as state Representative Lloyd George of Danville (left) and state Senator Joe Ray of Havana, who are inspecting the producers' gas machine of Dale Bliss of Bluffton (right). The deduction is available for systems that heat or cool buildings or provide hot water for the building.

ECONOMICS

The cost of constructing an anaerobic digester can be quite high, ranging upward to $5 per cubic foot. However, homemade systems can be constructed at much lower costs. In general, larger systems are more economi-

TABLE II

EXAMPLES OF LARGE-SCALE ANAEROBIC DIGESTER OPERATION WITH ENERGY BALANCES

INVESTIGATOR(s)	ENERGY BALANCE THERMAL OUTPUT/THERMAL INPUT
Pigg	1.67/1 — measured
Dynatech	3.7/1
Kroecker, et al.	0.51/1 — measured
K. Smith, et al. (Ecotope)	3.8/1 — based on measured input/output (with heat exchange)
	2.5/1 — measured (without heat exchange)

cal to own and operate than smaller systems. A number of variables can affect the economics of any particular system.

The most important thing to remember is the economic benefits of waste treatment and the gas produced by that treatment will have to outweigh the cost of owning and operating the digester system for it to be economically advantageous for its owner. See Table IV.

TABLE III
ESTIMATED DAILY MANURE AND BIOGAS PRODUCTION FROM ANIMAL WASTES

	Dairy Cows	Beef Cattle	Turkeys	Broilers	Layers	Hogs (Sow Units)	Hogs (Finishing)
Average Manure Production lb/day	85	50	.66	.14	.25	72	9
Total Solids lb/day	10.2	6.5	.165	.035	.083	7.20	.81
Volatile Solids (VS) lb/day	8.2	5.2	.135	.028	.05	5.76	.65
Biogas Production							
cf/lb VS	4.2	4.3	5.00	5.00	6.5	6.0	6.0
cf/animal	34.0	22.0	.66	.14	.32	34.0	3.9
No. Animals/gallon of Equivalent Energy/day							
LP gas	4.5	7.0	232	1095	479	4.5	39
Fuel oil	6.1	9.5	315	1488	650	6.1	53

TABLE IV
FUEL COST COMPARISON

FUEL	ENERGY CONTENT	COST	COST 100,000 Btu
L.P. Gas	92,000 Btu/gal.	$ .82/gal.	$ .89
Natural Gas	1,000,000 Btu/MCF	$3.00/MCF	$ .30
Gasoline	125,000 Btu/gal.	$1.35/gal.	$1.08
Diesel	140,000 Btu/gal.	$1.30/gal.	$ .92
Biogas	600,000 Btu/MCF	N/A	*

*The cost per 100,000 Btu for biogas must be below the cost per 100,000 Btu for the competing fuel, if the production of biogas is to be economically attractive.

APPENDIX A

CONVERSION FACTORS

MULTIPLY	BY	TO OBTAIN
Acres	43560	Square Feet
Atmospheres	14.696	Pounds/square inch
Bags Cement	94	Pounds of Cement
Barrels (U.S. Dry)	4.083	Cubic Feet
Barrels (U.S. Liquid)	4.211	Cubic Feet
Barrels (U.S. Liquid)	31.5	Gallons
Barrels (Oil)	42	Gallons
Boiler Horsepower	33475	Btu (mean)/hour
Boiler Horsepower	34.5	Pounds of Water Evaporated from and at 212° F per hour
Btu (mean)	251.98	Calories, gram (mean)
Btu (mean)	0.29305	Watt-hours
Btu (mean)/pound	0.556	Calories, gram (mean)/gram
Bushels (U.S.)	1.2444	Cubic Feet
Calories, Gram (mean)	3.98685×10^{-3}	Btu (mean)
Candle Power (Spherical)	12.566	Lumens
Centimeters	0.3937	Inches

MULTIPLY	BY	TO OBTAIN
Cubic Centimeters	3.531445×10^{-5}	Cubic Feet
Cubic Feet	1728	Cubic Inches
Cubic Feet	7.48052	Gallons
Cubic Foot of Water	62.37	Pounds
Cubic Inch	16.387162	Cubic Centimeters
Cubic Yards	0.76456	Cubic Meters
Gallons	231	Cubic Inches
Gallons	128	Ounces (Fluid)
Horsepower	2545.08	Btu (mean)/hour
Horsepower	550	Foot-Pounds/second
Inches	2.54000508	Centimeters
Kilowatts (Abs.)	1.341	Horsepower
Meters	3.280833	Feet
Miles	5280	Feet
Parts Per Million	0.058417	Grains/gallon
Pounds of Water Evaporated at 212° F	970.3	Btu
Proof	0.5	Percent Alcohol by Volume
Watts (Abs.)	3.41304	Btu (mean)/hour

GLOSSARY

Aerobes/aerobic — Bacteria that require the presence of free oxygen for their metabolic processes. Oxygen in chemical combination will not support aerobic organisms.

Anaerobes/anaerobic — Bacteria that do not require the presence of free or dissolved oxygen for metabolism. Strict anaerobes are hindered or completely blocked by the presence of dissolved oxygen; facultative anaerobes can be active in the presence of dissolved oxygen but do not require its presence. An aerobic system is one that requires oxygen. An anaerobic system is one that does not require oxygen.

Alkalinity — A quantitative measure of the capacity of liquids to neutralize strong acids. Alkalinity results from the presence of bicarbonates, carbonates, hydroxides, volatile acids and salt.

B.O.D. (Biological Oxygen Demand) — An indirect measure of the concentration of biologically-degradable material present in organic wastes. It is the amount of oxygen used by aerobic bacteria when allowed to degrade the organic matter in the presence of air at a constant temperature (20° C) for a specific time (5 days). It is expressed in milligrams of oxygen used per litre of liquid waste (mg/l) or in parts per million (p.p.m.).

Biodegradable — Organic matter that can be broken down by bacteria or other organisms is said to be biodegradable.

C/N (Carbon/Nitrogen ratio) — The weight ratio of carbon to nitrogen.

C.O.D. (Chemical Oxygen Demand) — An indirect measure of the amount of oxygen required to degrade the organic matter in water chemically. It is a measure of both the biodegradable portion and the portion of the waste that can only be oxidized chemically. It is determined by the amount of potassium dichromate consumed in a boiling mixture of chromic and sulphuric acids. The C.O.D. will always be higher than the B.O.D. value.

Calorific value — The energy content of fuels; it represents the amount of heat released when the fuel is completely burnt. It is measured in Btu's/cu. ft. (or per lb.) or Joules/cm³ (or per Kg.).

Liquefaction — The process of breaking down and dissolving organic solids, by the action of bacterial enzymes outside their cells.

Leachate — Water that flows through the soil or ground and ends up in a watercourse. If the water is contaminated initally and does not receive enough purification as it passes through the soil, the leachate can cause pollution. Similarly, if rain, etc. falls into a highly-organic sludge, it can carry polluting material with it.

Methanogenesis — The process of producing methane.

Methanogens — The bacteria that produce methane.

Oxidize/oxidation — The addition of oxygen to a molecule. In the case of organic matter, the molecule is often broken down to a smaller one. In aerobic organisms, the end product of oxidation or organic matter is carbon dioxide and water. When methane is burnt, it is completely oxidized to CO_2 and H_2O. The removal of hydrogen from a molecule is also a form of oxidation and thus the formation of methane is the methane-bacteria's way of obtaining oxidizing power.

Pathogen/pathogenic — Bacteria that cause disease both in animals and humans, e.g. salmonellae, which cause food poisoning, gastrointestinal inflammation or diseases of the genital tract.

pH — The measure of acidity or alkalinity. It is the logarithm of the reciprocal of the hydrogen ion concentration. pH seven is neutral; less than seven is acid; and more than seven is alkaline.

Septic tank — A single-story settling tank, in which the organic portion of settled sludge is allowed to decompose anaerobically without removal or separation from the bulk of the water flowing through the tank. Only partial liquefaction and gasification of the

organic matter is accomplished, and eventually the undecomposed solids will accumulate to the extent that solids removal is necessary.

Supernatant — The liquid that collects on the top of a waste or sludge after the solids are allowed to settle. By removal of the supernatant, the water plus dissolved organic matter can be separated from the solids.

Suspended solids — Solids that float or are in suspension in water and which can be removed by filtering.

Total solids — The residue remaining when the water is evaporated from a waste and dried at 110° C.

Volatile solids — The portion of the total solids that is driven off as volatile gases when the sample is heated to 600° C for one hour. Often synonymous with organic matter content.

SELECTED BIBLIOGRAPHY

Ables, Tom P. *A Technology Assessment of Anaerobic Digesters For Arkansas Farms*; Ozarks Regional Commission, 1100 North University, Little Rock, Arkansas 72205.1980.

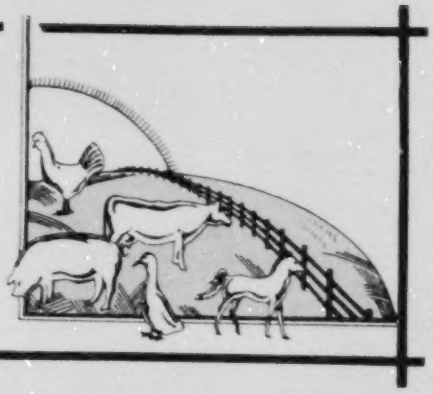
Griffis, C.L., Mote, C.R., and Keinholz, E. *Methane From Animal Wastes*. Agricultural Experiment Station, University of Arkansas, Fayetteville, Arkansas.1980.

Meynell, John, and Meynell, Peter. *Planning A Digester*. Schrocken Books, New York. 1978.

Jewell, William J. *Energy, Agriculture and Waste Management*. Ann Arbor Science, Ann Arbor, Michigan 48106. 1975.

Burford, John L. and Varani, Fred T. *Energy Potential Through Bio-Conversion of Agricultural Wastes, Final Report*. Four Corners Regional Commission. 1976.

Biogas Production on the Farm



BIOGAS PRODUCTION — IS IT FOR YOU?

Do you have a waste disposal problem?

Are you willing to spend the time and money necessary to install and maintain a biogas system?

Can you use the biogas produced?

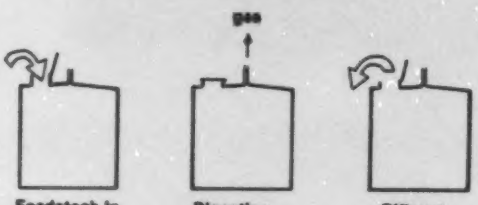
How much biogas can you produce?

What will the biogas be worth to you

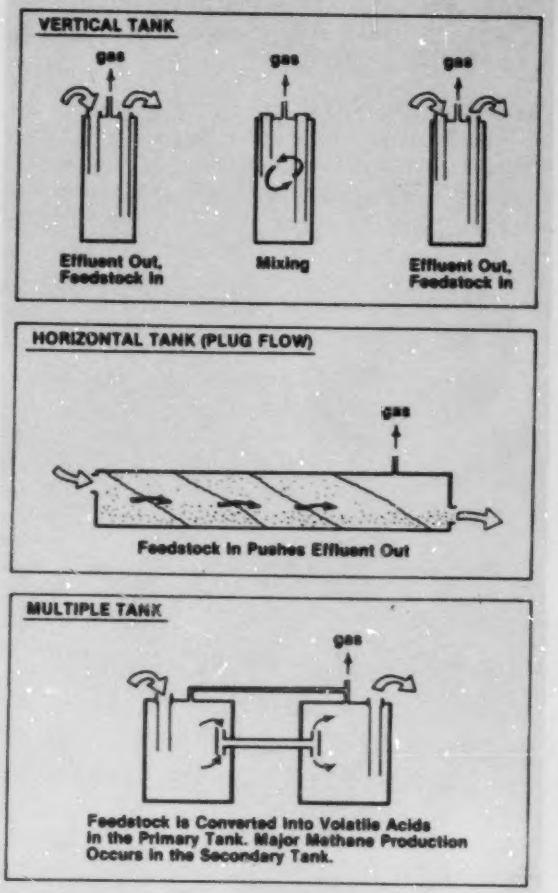
Yes, but is it a good investment?

Where do you go from here?

BATCH TYPE DIGESTER



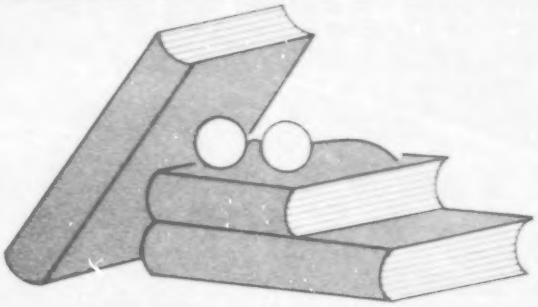
CONTINUOUS FLOW TYPE DIGESTERS



(Extracted from *An Introduction to Biogas Production on the Farm* available from the Arkansas Energy Office.)

Appendix A

Energy Bibliography



This is a list of publications available through the Arkansas Energy Office. These publications may be obtained by calling or writing the Energy Office. All publications are free of charge, unless otherwise stated.

ARKANSAS ALTERNATIVE ENERGY INDUSTRIES. Lists distributors, installers, designers and builders of wind, wood, water, and solar systems as well as conservation retrofits. 1983. 11 pp.

ARKANSAS ENERGY FUTURE Series:

ALCOHOL. Covers incentives for production, processes and regulations on producing alcohol. 1980. 33 pp.

COAL. History, geology and mining of Arkansas coal; glossary. 1980. 17 pp.

EARTH HOMES. Precautions to take in planning a home underground. Includes floor plans. 1981. 35 pp.

METHANE. Tells how to produce and use methane fuels. 1981. 32 pp.

OIL & GAS. Describes the history of Arkansas oil and gas industry and the geology of the deposits. 1980. 25 pp.

RESOURCE MAP. Arkansas has many marketable energy minerals, which are mapped in this brochure. 1980. 2 pp.

SOLAR ENERGY. Introduces the reader to basics in applying solar energy; lists resources for further study. 1981. 72 pp.

SOLAR GREENHOUSES. Gives plans for construction of a solar greenhouse to help reduce utility bills and grow plants at the same time; appendices; bibliography. 1980. 38 pp.

SOLAR HOT WATER. Offers plans for several types of solar water heaters for home use. 1981. 80 pp.

ARKANSAS ENERGY OFFICE. Gives information describing the programs and operations of the Arkansas Energy Office. 1983. 2 pp.

ARKANSAS RECYCLER'S GUIDE. Lists aluminum and paper recycling companies in Arkansas. 1980. 2 pp.

ARKANSAS RULES AND REGULATIONS FOR ENERGY EFFICIENCY STANDARDS FOR NEW BUILDING CONSTRUCTION. A compilation of the rules and regulations resulting from the Energy Policy and Conservation Act of 1975 (P.L. 94-163) as they apply to Arkansas; appendices. 1979. 110 pp. $4.00.

WORKBOOK FOR THE ARKANSAS RULES AND REGULATIONS FOR ENERGY EFFICIENCY STANDARDS FOR NEW BUILDING CONSTRUCTION. To accompany above. 1979. 49 pp. $4.00.

BATCH WATER HEATER. Tells about low-cost solar water heaters. 1983. 4 pp.

BUILDING ENERGY DESIGN TOOLS. Describes use of computers. 1983. 4 pp.

CHECK YOUR ENERGY CONSUMPTION. Gives a simple formula for calculating your energy consumption as recorded on your utility bills. 1980. 2 pp.

DESIGNING THE PASSIVE SUNSPACE. Lists features to include. 1983. 4 pp.

DIRECT GAIN SYSTEMS. Describes how to heat your home naturally. 1983. 4 pp.

EARTH SHELTERED HOUSES. Introduces reader to features of underground homes. 1983. 2 pp.

ENERGY FILMS. Lists films that may be borrowed from the Arkansas Energy Office, without charge, and resources for locating additional films to rent or buy. 1983. 4 pp.

FEATHERFOOT. Gives tips for driving efficiently and conserving fuel. 1979. 4 pp.

FILL IT UP. Offers tips on carpooling, a formula for estimating your carpool savings, and rules for "making it work." 1979. 6 pp.

IS RESOURCE RECOVERY FOR YOU? Offers municipal officials worksheets by which to estimate the profitability of burning solid waste instead of burying it. 1983. 32 pp.

INSULATION and COOLING. Tells how to figure insulation needs. 1983. 2 pp.

INTERIM REPORT ON WIND ENERGY IN ARKANSAS. Gives an overview, graphs and charts to assist the wind prospector in Arkansas. 1980. 2 pp.

KEEPING COOL. Tells how to provide proper house ventilation and cooling without a mechanical system. 1983. 6 pp.

MOVABLE INSULATION. Tells how to control loss of heating and cooling by sealing windows. 1983. 2 pp.

NATURAL COOLING. Describes natural cooling measures for your home. 1983. 2 pp.

PASSIVE SOLAR RETROFIT. Discusses additions you could make to a home that supply energy needs. 1983. 2 pp.

RECYCLING OIL. Tells how to drain oil from your car and recycle it, to conserve our nonrenewable resources. 1982. 4 pp.

SAVE ENERGY; CUT TAXES. Describes the valuable tax incentives provided by the Arkansas and United States governments to encourage home energy conservation and development of alternative energy sources. 1981. 4 pp.

SHAREAVAN. Tells about the comfortable way to save money; the advantages and how-to's of vanpooling for the employer and employee. Kit. 1980. 6 pp.

SLICK, EASY, MONEY. Describes how to earn money from recycling waste oil in Arkansas today. 1982. 4 pp.

SMALL DAM SURVEY. Lists a statewide inventory of undeveloped and partially-developed hydropower sites that would generate under 30 megawatts. 1981. 4 pp.

SOLAR HOMES FOR ARKANSAS. Gives eight house plans that depend on natural methods of heating and cooling as much as possible. 1983. 26 pp.

SOLAR WATER HEATERS CONSUMER TIPS. Figures savings from using solar energy. 1983. 2 pp.

STARTING A DRIVER-OWNED AND OPERATED VANPOOL. Contains all the information you need to start your own vanpool, and earn money at the same time you save energy. 1980. 2 pp.

SUCCESSFUL SOLAR BUYING. Offers a guide to buying solar equipment. 1982. 4 pp.

THERMAL ENVELOPE HOUSES. Describes features of this energy-saving type of home. 1983. 2 pp.

TIPS FOR ENERGY SAVERS. Provides a checklist of places in your home that may leak energy and tells how to stop energy losses and save money. 1982. 4 pp.

VENTILATION. Suggests ways to cool a home without mechanical systems. 1983. 4 pp.

WOOD HEATING. Tells what you should know about buying wood and wood burners, and the safe operation of wood-burning equipment; gives a checklist to help you get started. 1983. 4 pp.

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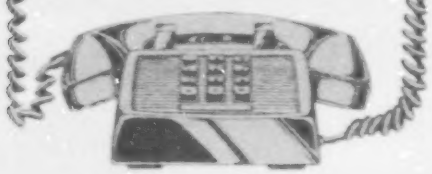

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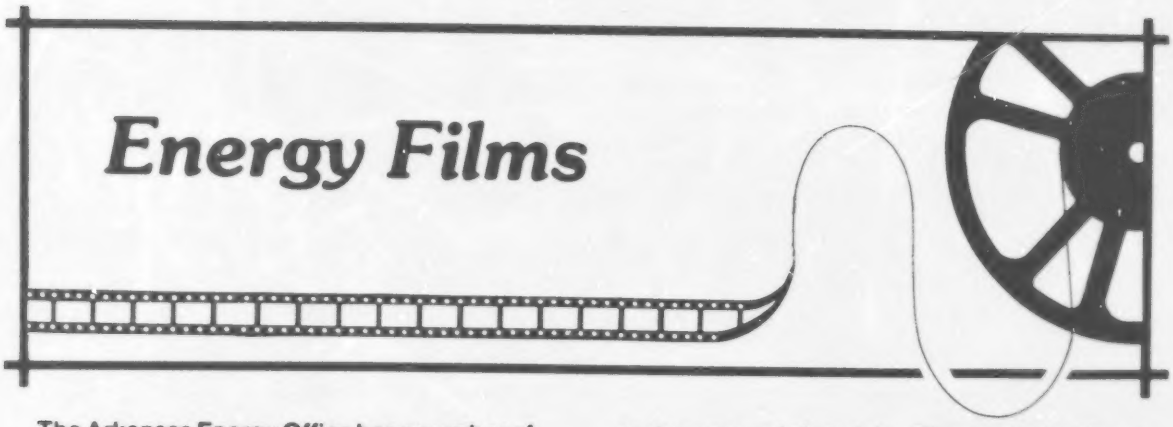
Little Rock, Arkansas 72201

Appendix B

Energy Films



The Arkansas Energy Office has a number of 16 mm films, filmstrips and slide presentations available on loan, free of charge. All are on the general topic of energy. Ordering information follows the list.

DECISION: ENERGY FOR THE FUTURE
12 minutes — 16mm — color — Intermediate/ Adult — Bullfrog Films

Gas lines or no gas lines, many Americans refuse to believe that we face a shortage of fossil fuels. This amusing animated film uses graphs and manipulates screen time to demonstrate to children and adults that our dependence on fossil fuels is an extremely recent phenomenon which, if continued, will lead to disastrous shortfalls. But there is a clear alternative: to switch to renewable energy sources. We should act now so that we can be proud to say, "It all began with us."

THE ENERGY CRISIS
Filmstrip — Junior High — Educational Activities, Inc.

Part One lists some reasons why we must search for alternatives to oil and describes several possibilities. It is designed to help us recognize that most of the energy on earth comes from the sun. Part Two lists reasons why energy was conserved in the past and ways it can be conserved in the car, home and personal lifestyle today. This part is designed to help us recognize ways energy is commonly wasted and summarizes the benefits of conservation.

TURN A HANDLE; FLICK A SWITCH
122 minutes — 16 mm — color — Elementary/-Intermediate — Churchill Films

The film is in three parts, which deal with water, gas and electricity. Three principal concepts are dealt with; where water, gas and electricity come from, how they get to our homes and how we use them there. Places to stop the projector allow the teacher to involve the children in discussion. Each sequence is begun by an absurd high-speed scene in which children provide water, heat and light as our forebears did.

FEATHERFOOT
26 minutes — 16 mm — color — Junior High/-Adult - American Institute of Driving Efficiency

Test your Driving Efficiency Quotient as you view this film about energy-saving driving and car maintenance habits. Developed by Honeywell Corporation, Featherfoot training reduced the company's transportation energy use by 13 percent. At today's gasoline prices, that's a lot of money! Test forms, brochures, mileage calculators and mileage records are provided with the film. Viewers are encouraged to practice the Featherfoot driving techniques they learn from the film and to get in the habit of keeping track of their miles per gallon to see what a difference Featherfoot driving can make.

HOTTEST SHOW ON EARTH
25 minutes — 16mm — color — MacMillan Films, Inc.

Uses animation, special effects and humor to explore why and how we should insulate our homes. Produced by the National film Board of Canada. Entertaining, but not too informative, this film would make a good warm-up introduction to a serious workshop on home insulation.

RUNNING ON EMPTY —
THE FUEL ECONOMY CHALLENGE
27 minutes — 16 mm — color — National

Audiovisual Center

This film introduces us to a variety of methods that average drivers in average cars can practice — as they travel city streets, country roads, and major highways — to achieve maximum savings in gasoline and in money.

SAVING ENERGY AT HOME

13 minutes — 16mm — color — Junior High/Adult — Ramsgate Films

Major sources of energy waste around the house are pinpointed and specific tips are provided on how to control home energy consumption and fuel bills. On-the-street interviews demonstrate the new attitude toward energy usage and its effect on the American lifestyle.

20 MILES FROM EVERYTHING

20 minutes — 16 mm — color — Federal Highway Administration

A look at five demonstration projects showing innovative methods designed to solve the transportation problems of rural America.

VANPOOLING

17 minutes — 16 mm — color — U.S. Department of Energy

Vanpooling saves energy and money, reduces pollution and is a convenient and comfortable way to get to and from work. Whether the vanpool is operated by an individual or is provided by an employer or government agency, commuters can benefit from vanpooling.

LEARNING ABOUT SOLAR ENERGY

26 minutes — 16 mm — color — Elementary/Intermediate — Paramount Communications

A group of children builds a small house to experiment with energy from the sun. They cook food on a fire and on a solar cooker to demonstrate the use of indirect and direct solar energy. They play with different-colored paints to investigate the relationship between color and heat. As they experiment with solar panels, fuel pellets and a toy steam engine, they demonstrate both conventional (fossil fuels and electricity) and unconventinal (solar panels and solar cells) sources of energy. Photosynthesis and energy cycles, like the food chain, are explained. A diagram illustrates how fossil fuels are created. The film emphasizes that life on Earth would be impossible without the sun which, directly or indirectly, is the source of all energy.

SOLAR ENERGY: THE GREAT ADVENTURE

26 minutes — 16mm — color — Junior High/Adult — National Audiovisual Center

A look at our nation at its innovative best. Eddie Albert introduces us to an unusually diverse group of people who have developed their own solar energy systems, both urban and rural. From New England to Missouri and on to California, the film presents a lively look at American ingenuity at the grassroots. We meet a builder and a banker, a farmer and a teacher, inner-city workers and industrialists, enterpreneurs and tinkerers. All are seeking new and better ways to put the sun to work. A "hydronic" solar heating and hot-water system, solar financing, an energy self-sufficient farm, windmills and wind turbines, wood energy, solar education, urban solar systems and job opportunities are examined. "There will be a great adventure for this country as we move into the next century and turn increasingly to renewable sources of energy as a replacement for fossil fuels."

THE SOLAR FILM

9 minutes — 16 mm — color — Junior High/Adult — Pyramid

The Solar Film combines elements of drama, technology and striking visual imagery to present the vast potential in the sun's energy. The film uses animated, live action and still photography to tell a story in three parts: how the sun made the earth as we know it today; how humankind has dangerously exploited the resources created by the sun; and how the sun can provide us today with yet another energy source that is clean, safe and ever-renewable. Solar energy, and the technology to use it, are ready and waiting!

SOLAR IN ARKANSAS

45 minutes — slides — color — Junior High/Adult — North Arkansas Community College

This slideshow with taped narration describes homes, mostly in Northwest Arkansas, that use passive and active solar principles in their design, as well as alternative energy projects such as an alcohol fuel distillery, a methane digester and several windmills. The show was prepared by Stephen Cook of North Arkansas Community College at Harrison.

SOLAR PROMISE

22 minutes — 16mm — color — Junior High/Adult — Bullfrog Films

Solar energy can heat our homes, buildings and water with active or passive systems, whether new or retrofit, in any climate, even the coldest and cloudiest. And solar can be cost-effective, particularly low-cost, do-it-yourself technology such as an attached solar greenhouse. Not only can it heat your home, but you can grow food year round. Solar principles are not new. The Anasazi of Mesa Verde (Arizona) used passive solar building techniques to keep their dwellings a constant 65° year round. At the turn of the century, one-third of the homes in Pasadena, California used solar-heated water. These old principles and techniques are easily adapted and refined for modern use. Diagrams and examples of systems in use from Vermont to New Mexico show how solar collectors, trombe walls, greenhouses and other solar systems work.

THE POWER TO CHANGE

28 minutes — 16mm — color — Junior High/Adult — Third Eye Films

Tells about human-scale solutions to social and economic problems — appropriate technology. Visits a farmers' market in Tennessee, a composting project in New York, a solar community of Davis, California, a wind-mobile in Michigan, an alternative energy company in California, and a windmill raising in Massachusetts.

LOVINS ON THE SOFT PATH

36 minutes — 16mm — color — Grade 9/Adult — Bullfrog Films

Offers an analysis of the energy problem, by Amory and Hunter Lovins, and tackles four revealing questions: "How much energy do we need?", "What kinds of energy?", "Where can we get it?", and "Where do we start?"

WEATHERIZE YOUR HOME

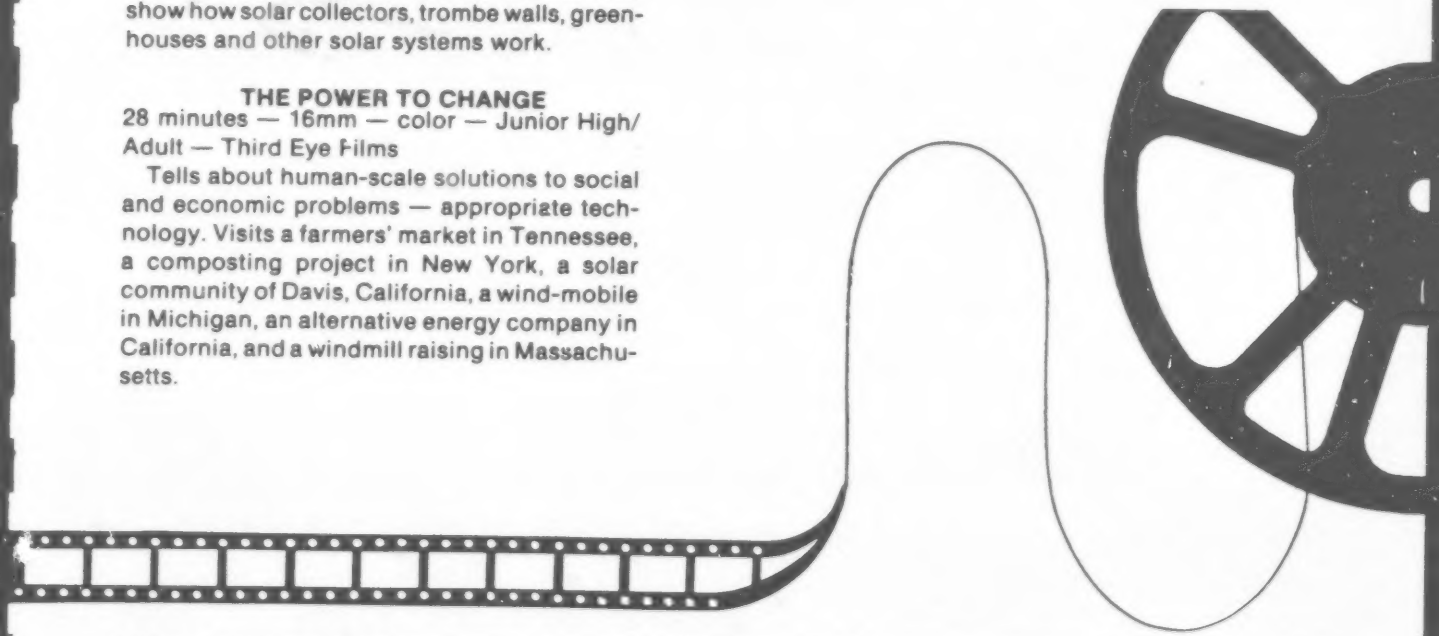
18 minutes — 16mm — color — Media Resources Center

Offers a wealth of ideas for improving a home's energy efficiency, explanations of R-value and heat loss, and step-by-step instructions for caulking, installing vapor barriers, and insulating attics, floors, and water heaters.

BUILDING THE BROOKHAVEN HOUSE

25 minutes — 16mm — color — High School/Adult — Bullfrog Films

Shows a passive-solar demonstration project, a house designed to be an attractive and marketable home in the areas of the United States where energy costs are dominated by space heating. It's a documentary about the concepts and construction practices used in passive-solar homes, for builders, architects, engineers, students and the solar-oriented public.



WHO MAY BORROW

Educational, civic, church, library, professional, youth activity, commercial, industrial, and government organizations are invited to borrow films. This service is intended for group showings — but not for personal home use.

LOAN REQUIREMENTS

Please help us and follow these simple requirements:

1. Use a good projector and an experienced operator.

2. Please do not cut out any scenes.

3. Films do break and occasionally will require splicing. We prefer that damaged films be returned to us for professional repairs. Do not use Scotch tape for emergency splices. Damage should be reported in a note when returning the film, so that repairs may be made before it is shipped to the next borrower.

4. Borrowers planning to show a number of films on a protracted schedule should request delivery of specific films on a staggered schedule, to help us serve other borrowers.

5. Films are booked for specific users and dates. Please do not send the films to others. Return each film promptly by the fastest method. We like to honor all requests.

6. Films are shipped from the film library at government expense, but return shipment charges are paid by the borrower.

7. Rewind films for return.

HOW TO ORDER

The Arkansas Energy Office film library enjoys heavy patronage throughout the year, so it is important that borrowers needing particular titles make their requests as far in advance of their scheduled showing date as possible. Since some titles are booked solidly in advance for several months, borrowers should attempt to specify at least two alternate titles or an alternate showing date for a film that is strongly desired. To order, call or write:

Arkansas Energy Office
One State Capitol Mall
Little Rock, Arkansas 72201
371-1370
or
1-800-482-1122